ENGINEERING TOOLS AND PROCESSES

A Study of Production Technique

By

HERMAN C. HESSE

Dean of Engineering, Valparaiso University

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Dedicated to my wife

HELEN

who has been a constant inspiration
during the preparation of this book.

PREFACE

In recent years there has been a tendency to eliminate or curtail college laboratory courses dealing with wood shop, machine shop, and foundry practice and technique. This situation has developed because the professional and cultural content of the average engineering curriculum has been greatly increased, and also because it is practically impossible to include in a practice or laboratory course the new material and diversified methods brought about by mass production.

This text has been developed for a one-semester lecture or reading course in engineering shop processes and practices. The first three chapters offer a survey of basic materials, elements and devices, to acquaint the student with engineering nomenclature and terminology. This treatment is necessary not only to facilitate the study of manufacturing machinery and tools, but also because courses of this character generally precede technical and professional studies. The text then takes up the usual shop processes and machines, continues with discussions of production machinery and processes not ordinarily presented in college laboratories, and illustrates the application of these methods to the manufacture of specific parts. The text concludes with a discussion of important considerations in design and the manner in which they affect production economy and feasibility. The presentation is pictorial wherever possible although adequate explanatory material is included. To facilitate study and recitation and to develop the application of the principles studied, numerous questions and problems are included. These are arranged so that odd- and even-numbered questions cover essentially the same text material to enable the instructor to use different sets of questions for concurrent and consecutive student groups.

This book should also be useful as a supplement to the usual texts in Engineering Drawing, Machine Design and Structural Design. Employed as reference material in these courses, it will acquaint the student with the possibilities and limitations of manufacturing methods and may serve as a substitute for the shop experience that is so essential to successful design and detail procedure.

University of Virginia
July 1941

HERMAN C. HESSE

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CHAPTER 1

ENGINEERING MATERIALS

1. A survey of commonly-used engineering materials is essential to the study of engineering processes and practices. This treatment is of importance not only because an extensive variety of materials is used in practice, but also because the characteristics of a material affect manufacture and application. The **characteristics** of a material are those features or qualities such as strength, hardness, and elasticity, which render it applicable or non-applicable to engineering use and practice. Material characteristics often depend upon both the chemical composition and the physical structure of the substance in question. Lead and nickel, for example, have similar crystalline structure but their characteristics differ because of different chemical composition. On the other hand, diamonds and graphite have the same chemical composition but their physical structures differ as a result of processing—either natural or artificial.

2. One of the most important characteristics of an engineering material is its **strength,** by which is meant the ability of a part made of the material to resist externally-applied forces. The internal resistance offered by a part to an externally-applied force is termed a **stress.** There are three types of so-called "simple" stresses—**tension, compression,** and **shear.** Fig. 1-1 shows a bar of square cross-section subject to two sets of external forces equal in magnitude, opposite in direction, and acting away from each other. These forces induce a *tensile stress* in a plane perpendicular to their line of action. Fig. 1-2 shows the mode of failure of this bar. Fig. 1-3 shows a similar bar with forces acting towards each other, inducing a resistance within the bar that is called a *compressive stress.* Fig. 1-4 is representative of compressive failure of soft, ductile materials, while Fig. 1-5 indicates the possible compressive failure of brittle materials. Fig. 1-7 shows a bar subjected to the action of a pair of equal, opposite, parallel forces, effecting a "scissor-like" action on the bar, and inducing a *shearing stress* on a section parallel to the force lines, as illustrated in Fig. 1-8 and Fig. 1-9.

3. The **unit stress** in tension, compression, or shear is equal to the load distributed over the section divided by the cross-sectional area of the bar. In Fig. 1-1, if the bar is 3″ x 3″ in cross-section, and the external forces are equal to 18 tons, the unit stress is equal to $18 \times 2000/(3 \times 3) =$ 4000 pounds per square inch of area, generally specified as 4000 psi. This

method of stress measurement is obviously better than a consideration of the total load. For example, a 4″ x 4″ bar subjected to a total force of 24 tons has a unit stress of $24 \times 2000/(4 \times 4)$, or 3000 psi, which is less than that of the preceding example, although the total load is one-third greater.

The **ultimate strength** of a material is that unit stress beyond which failure by rupture may be expected. Ultimate strength is determined experimentally by employing some form of testing machine. In practice, engineering materials are not stressed to their ultimate strength, since lack of homogeneity of the material, inadequate knowledge of the loading, and

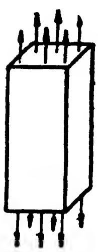


FIG. 1-1.

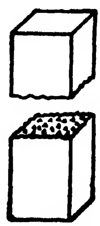
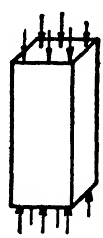


FIG. 1-2.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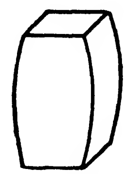
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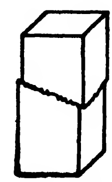
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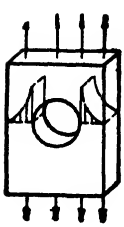
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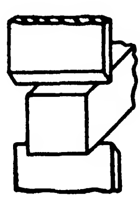
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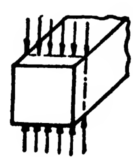


FIG. 1-8.

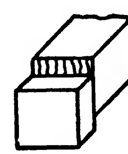


FIG. 1-9.

changes in the structure of the material on account of manufacturing processes all contribute to uncertainty as to the point of failure of the part in question.

The **allowable unit stress** of a material is the stress to which it may be safely subjected to preclude the possibility of failure in service. The ratio of the ultimate strength and the allowable unit stress is termed the apparent factor of safety. This factor may vary from 4 to 20 or more, depending upon the structure of the material (brittle, fibrous), the character of the applied load (steady, fluctuating, shock), the effect of abrupt changes in the form of the part, the possibility of danger to life or property if unexpected failure occurs, and many other reasons. As an illustration, if the ultimate strength of the bar material of the preceding examples is 60,000

psi, the factor of safety for the 3″ × 3″ bar is 15, and for the 4″ × 4″ bar is 20.

4. Induced stresses of more complex character are really combinations of the three types of simple stress. Fig. 1-10 shows a beam supported at both ends with a concentrated load at the center. The deflection of the beam under the load is illustrated in Fig. 1-11. A typical cross-section of the beam is subjected to a direct shearing stress, a compressive stress at the top of the beam (caused by the shortening of the fibers), a tensile stress at the bottom of the beam (caused by an elongation of the fibers), and a shearing stress along the length of the beam (caused by the tendency of the beam layers to slide on each other). Fig. 1-13 illustrates similar effects in a column in which the length of the member so exceeds the dimen-

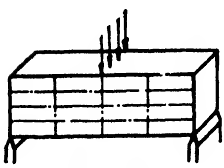


Fig. 1-10.

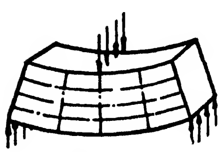


Fig. 1-11.

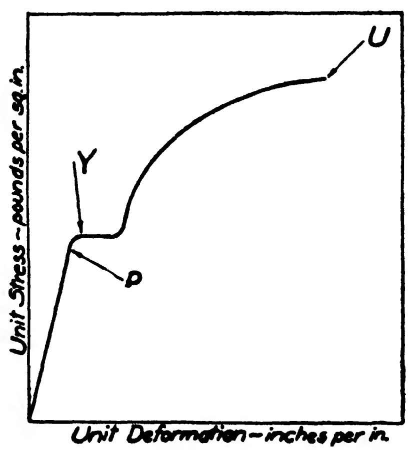


Fig. 1-12.

Fig. 1-13.

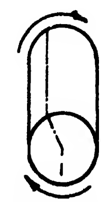


Fig. 1-14.

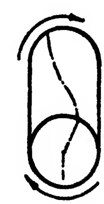


Fig. 1-15.

sions of its cross-section that the tendency to failure is that of a buckling or bending, rather than of a pure compressive stress. The foregoing stresses are often referred to as *flexural stresses*. Fig. 1-14 and Fig. 1-15 illustrate the effect of twisting forces on a circular shaft, which induce shearing stresses between the adjacent cross-sections of the shaft. These stresses are referred to as *torsional stresses*.

When the cross-section of a bar subjected to a tensile stress is nonuniform, as illustrated in Fig. 1-6 which shows a bar of rectangular section with a circular hole through it, the stresses at the minimum section are often increased nonuniformly as far as the actual area under load is concerned. Such *stress concentrations* are generally determined experimentally through the medium of transparent plastic models, and investigations concerning them are beyond the scope of elementary mechanics.

5. Fig. 1-12 illustrates the graph of a tension test specimen—the unit stress in pounds per square inch of cross-section being plotted against the increase in length per unit length of the specimen. Point *P* represents the **proportional limit,** beyond which the deformation increases at a more rapid rate with respect to uniform increases in the loading. This limit is often erroneously called the elastic limit. The proportional limit is one beyond which the proportionality of unit stress and deformation no longer applies, while the **elastic limit** is properly the limit beyond which the material does not regain its initial dimensions upon release of the loading. Point *Y* represents the **yield point,** at which, in most ductile materials, there is a marked increase in length without any great change in the applied load. Beyond point *Y* an increase in load causes an increase in length until the point *U,* which represents the ultimate strength of the material, is reached.

A knowledge of the proportional and elastic limits of a material is necessary for design and application, since allowable stresses employed in machine and structural design are usually kept below these limits. The yield point is of importance because several engineering processes such as forging and wire-drawing are possible by virtue of the fact that steel and other materials may be permanently deformed, either in a heated or a cold state, into shapes that may be utilized in practice.

6. Another important characteristic of engineering materials is **elasticity,** by which is meant the capacity of the material to resist externally-produced deformations without permanent change of form. Most engineering design involves an appreciation of the fact that elastic deformations are attendant upon applied stresses in structures and machines. Elasticity is generally evaluated by means of the *modulus of elasticity,* which is the ratio of the unit stress to the unit deformation within the proportional limit of the material in question.

Stiffness may be considered as resistance to deflection or deformation and is an important characteristic in the design of members where accurate alignment under load is required.

7. **Plasticity** is the characteristic by which materials may be permanently deformed into shapes that may be conveniently utilized in engineering practice, generally by processes that involve a limited amount of heat or pressure, or both. Such permanent deformation is generally accomplished by inducing stresses beyond the yield point of the material, although subsequent treatment may restore many of the elastic characteristics. In some materials, such as lead, for example, plasticity may imply an almost total absence of elasticity.

Malleability is a form of plasticity which permits material to be rolled or hammered with ease into thin sheets.

Ductility is a form of plasticity that permits material to be subjected to large deformations, with or without the application of heat, and still retain considerable strength, and is the characteristic that is of importance in processes such as wire-drawing. Many steels used in wire-drawing permit definite changes in shape and size without fracture. In some instances the unit tensile strength of wire steels actually increases as the diameter of the wire is reduced by successive drawing operations.

8. Fusibility is the characteristic by which materials—metals in particular—become fluid through the application of heat. It is very important because of its utility in *casting* processes, in which material is given definite shape by first rendering it fluid and then pouring it into suitable shapes or *molds* and allowing it to cool. Fusibility is also important in such applications as fusible plugs for pressure vessels and safety fuses for electrical devices where excessive heat or current will cause failure of an easily-replaceable part.

Refractoriness is a diametrically opposite characteristic to fusibility, but is of great importance in boilers, furnaces and crucibles, in providing capacity to resist changes in form in the presence of heat.

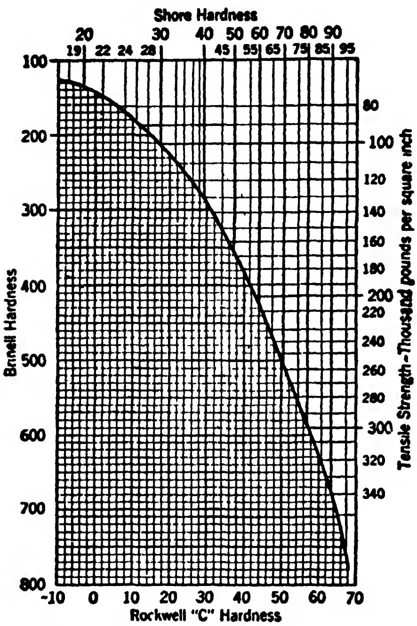
9. Hardness is a measure of the ability to resist surface penetration. There are several methods for measuring or evaluating the hardness of a specimen.

The Brinell hardness number measures the resistance of a metal to permanent indentation by another body. The Brinell machine is a device whereby a hardened steel ball is forced into a flat surface of the specimen under a definite pressure for a definite length of time. The Brinell number, N, is found by dividing the applied load in kilograms by the spherical area of the indentation in square millimeters. Brinell numbers of some metals are: lead—5; aluminum—40; copper—89; gray cast iron—180.

The Rockwell hardness test for soft metals is similar to the Brinell test, but hardness numbers are read from an arbitrary B scale on the Rockwell machine. In the Rockwell C test, which is used for alloy and other steels, the penetrating point is a diamond cone, hardness numbers being read from the C scale on the instrument. The Rockwell superficial hardness tester is similar to the standard Rockwell instrument, but employs a smaller load and makes a shallower indentation; it is used in determining the hardness of thin sheets, and for parts having only a surface hardness, such as casehardened steel.

The Shore Scleroscope determines hardness by measuring the height of rebound of a diamond-pointed weight from a flat surface of the material in question. The height of the rebound is proportional to the hardness of the metal, and the Scleroscope hardness number is read from an arbitrary scale on the instrument.

Fig. 1-16 illustrates the relation between the tensile strength of a structural alloy steel and the various hardness numbers. It is possible to set up such a curve for any given type of ferrous alloy. The use of this curve for the specified alloy permits rapid inter-conversion betweer the various hardness scales and the tensile strength of the material. Fc example, a sample has a Brinell hardness of 500, a Rockwell hardness of *C* 50 and a Shore hardness of 70; its probable tensile strength is 255,000 psi.



International Nickel Co

Fig. 1-16. Approximate Relation between tensile strength and hardness.

It is important to note that this type of curve, Fig. 1-16, applies only to the particular alloy for which it has been derived. Thus Fig. 1-16 should be used only for the useful series of low-nickel alloy steels. The basic purpose of such charts is to simplify routine testing, because hardness tests are more easily performed than tensile strength tests. In addition, the test may be made on the finished member, since tensile testing destroys the necessarily specially shaped sample. Thus it is conceivable that a whole series of such curves could be made to cover particular alloys—one for 3% chromium alloy steel, one for duralumin, one for steel, etc.

10. Resistance to abrasion is a characteristic of materials that is closely allied to hardness but has somewhat differing manifestations. For example, manganese steel is not necessarily very hard, but it has great resistance to abrasion. This characteristic is somewhat dependent upon the quality or character of the surface finish, and very definitely dependent upon the presence or absence of a suitable lubricant between moving contacting surfaces. No investigation of abrasion resistance or *wear hardness* has as yet succeeded in determining its relation to other characteristics, although it is evident that qualities such as hardness are important factors in the problem. Generally speaking, unlike materials in contact offer better wear resistance than like materials, with the notable exception of well-lubricated cast iron parts. Wear resistance may change materially over

long periods of time; well-lubricated cast iron and hardened steel surfaces in contact appear to improve in wearing quality the longer they run together, while cast iron moving on soft steel effects extensive abrasion of the steel the longer the parts operate together.

11. **Machineability** is a measure of the ease with which material may be cut. It is a very complex characteristic, but is of great importance. Its effect may best be illustrated by several examples. For instance, cast iron is definitely harder than copper, but is easier to machine because of its brittle nature, as contrasted with the more ductile copper. Again, some of the plastics are much softer than most metals but are more difficult to machine because the abrasive nature of the material results in excessive tool wear. Machineability depends not only upon various other characteristics of the material being cut, but also upon the hardness and other characteristics of the cutting tools employed.

12. The ability of an engineering material to receive and retain an acceptable **surface finish** is a characteristic that is becoming increasingly important in modern design. This feature is often associated with another characteristic, that of **resistance to corrosive action**, although each characteristic is important independently.

High-friction qualities as in brake-band materials, and anti-friction qualities as in sliding bearings, are important **surface-effect** characteristics. The ability of a material to retard the transmission of heat or electricity, to retard the transmission of sound, or to *dampen* vibrations, are all illustrations of characteristics that are important for their **insulating** qualities. The converse of this quality, the characteristic of high electrical or heat conductivity with minimum energy losses is, of course, of equal importance.

13. The characteristic of economy or **cost** is rather complex. It includes not only the initial cost of the material itself but also the cost of fabrication, maintenance, sales, and in some instances the cost of replacement. Machineability, resistance to corrosion and abrasion, surface finish, etc., have much more effect on the characteristic of cost than might be supposed. In some instances, particularly in the aircraft industry, weight reduction is so essential that materials of higher cost, and consequent higher part cost, are employed to attain the desired result.

The characteristic of cost is the limiting factor in all engineering applications, with three possible exceptions: (1) when extreme safety is desired; (2) when extreme precision is required, as in the case of some scientific equipment; and (3) when national safety is at stake, as in time of war. In general, it may be said that the best material for a given application is the one that will function satisfactorily at the lowest cost for the finished product.

14. Engineering materials may be conveniently classified under three general heads: **ferrous metals; non-ferrous metals;** and **non-metals.** The ferrous metal classification includes iron and steel and their alloys; the non-ferrous group covers lead, copper, zinc, and their alloys; and the non-metals include both natural and synthetic products that are of importance in engineering practice.

15. Articles of **cast iron** are made of *pig iron* which is received from the blast furnace in the form of billets or pigs, remelted in a cupola or other form of remelting furnace, and poured into suitable molds. Cast iron is defined as "iron containing so much carbon that it is not malleable at any temperature." The carbon content varies between 2% and 4%. The average carbon content for commercial cast iron of ordinary machining qualities is 3.5%. There are two principal forms: **gray cast iron,** in which most of the carbon is present in a free or uncombined state and which is comparatively easy to machine, and **white cast iron,** which is difficult to machine because most of the carbon present is in chemical combination with the iron.

Gray cast iron is the iron of general commercial use, having ultimate tensile and compressive strengths of about 18,000 psi and 90,000 psi, respectively. It weights about 450 pounds per cubic foot, has good wearing qualities, can be cast in comparatively complicated shapes in sand molds with little shrinkage in cooling, and can be easily machined. The material has high vibration-damping qualities, and can therefore be employed in preference to steel for an application such as a compressor frame It is comparatively brittle, however, and for that reason should not be employed for members subjected to shock or fluctuating loads. It is generally desirable to employ cast iron in such a manner that the stresses within the part shall be in compression, because of the weak tensile strength of the material. Cast iron is the cheapest of the metals and is therefore used whenever weight is desirable or unobjectionable.

White cast iron is employed principally for the production of malleable iron castings. The iron is cast into sand molds, cooled, and the casting is then packed at an elevated temperature in a material which may be of an oxidizing character, thus precipitating the chemically combined carbon into graphitic form. The average ultimate strength of the resulting malleable iron is 50,000 psi. in both tension and compression. **Malleable** iron parts are tough and can often be employed to replace steel forgings. Malleable iron is employed when parts of rather complicated shape are required; parts which may be more readily produced by casting than by forging, but for which gray cast iron is unsuitable on account of its low tensile strength and brittle nature.

Alloy cast irons are coming into extensive use although they are more expensive than gray iron. *Mechanite* is essentially a gray iron which is graphitized at the ladle by the addition of calcium silicide. It has ultimate tensile and compressive strengths of 35,000 psi and 135,000 psi, and it is possible to increase the tensile strength to 110,000 psi by suitable heat-treatment of the castings. *Ni-resist,* a nickel-chromium cast iron, is a corrosion-resistant material of about the same strength and machining qualities as gray iron. *Duriron* is an acid-resisting iron obtained by increasing the silicon content of white cast iron to about 14%. It is especially resistant against the corrosive action of all the commercial acids (hydrofluoric excepted). Its tensile strength is about one-half that of gray iron, but it is so hard that it can be machined or finished by grinding only. *Semi-steel* is made by adding from 20% to 40% of scrap steel to gray iron. The ultimate tensile and compressive strengths are 28,000 psi and 110,000 psi. Semi-steel may be rendered ductile by annealing or softening at a temperature of about 800° F., but its tensile strength is thereby reduced by about one-third.

16. **Wrought iron** is a ferrous product that is produced by oxidizing the carbon from molten iron, and then hammering or rolling the heated iron while in a plastic form, and thoroughly "working" the slag into the product. The carbon content is generally less than 0.1% and the material must contain not less than 1% slag. The slag content and the comparatively pure nature of the iron provide the principal characteristic of wrought iron—its high resistance to corrosion. Wrought iron is quite ductile and can be easily rolled, drawn, forged and welded. It cannot be cast since the necessary remelting process destroys the slag-impregnated nature of the material. Its initial cost is greater than that of cast iron or steel, but wrought iron is extensively used for rivets, and for steam and water pipes where its characteristic of high resistance to corrosion is of value.

17. **Steel** is a ferrous material with a carbon content intermediate between wrought iron and cast iron. The carbon in steel is in a chemically combined form, and varies from 0.1% to 1.0%.

Cast steel normally contains about .45% carbon, and is used to replace cast iron when castings of considerable strength are required. Steel castings are more difficult to produce than those of cast iron, because of greater shrinkage and the likelihood of defects in the casting. They are extremely difficult to machine unless annealed.

Forged steel is steel that has been hammered, drawn, pressed or rolled in the process of manufacture of a particular part. It is classified according to its carbon content since carbon is the most important element in forged steel. The important classifications are as follows:

Below 0.15% carbon—Very *mild* steel—stock for screw manufacture; cold-rolled steel.
0.15 to 0.30% carbon—*Mild,* or *low-carbon* steel—structural shapes and boiler plate material.
0.30 to 0.60% carbon—*Medium-carbon* steel—machinery steel for shafts and other machine parts.
Above 0.60% carbon—*Hard* or *high-carbon* steel—tool steel for cutting tools, springs, etc.

The weight of steel is approximately 490 pounds per cubic foot. Unlike cast iron, the tensile and compressive strengths of carbon steels are approximately equal. The strength varies, in general, directly with the carbon content, from about 55,000 psi for a 0.1% carbon steel to about 150,000 psi for a 1.0% carbon steel. Carbon steels can be forged and welded but the machineability depends to some extent on the carbon content. High-carbon steels can be heat-treated to improve their strength characteristics, and can be hardened to provide cutting edges by heating and subsequent quenching.

Alloy steels are those in which some alloying element in addition to the carbon is present in some appreciable quantity. There are numerous alloying materials, each of which has a definite effect on the characteristics of the steel. Nickel gives increased strength and hardness without any proportionate decrease in ductility. Silicon increases the strength if present in quantities not exceeding 2%. Chromium increases the strength and hardness of the steel at the expense of a slight decrease in ductility, if present in quantities not exceeding 2%. Vanadium increases the toughness and the resistance of the alloy steel to shock. Tungsten and molybdenum enable the steel to be hardened in air; the presence of molybdenum improves the strength, ductility and machineability. About 14% of manganese will provide a very ductile, abrasion-resistant alloy steel. Copper increases the strength of low-carbon steels and is employed to provide resistance to corrosion in some of the so-called *copper-bearing* steels.

Designation numbers for alloy steels have been developed by the Society of Automotive Engineers and are now in general use. The S.A.E. designation number consists of four figures, of which the first indicates the classification of the steel, the second the approximate percentage of the principal alloying element other than carbon, and the last two the "points," or hundredths of one percent of carbon. The primary classification figures are:

1—Plain carbon steels
2—Nickel steels
3—Nickel-chromium steels
4—Molybdenum steels
5—Chromium steels
6—Chrome-vanadium steels
7—Tungsten steels
9—Silico-manganese steels

Thus—S.A.E. 1045 is a plain carbon steel containing 0.45% carbon; S.A.E. 2335 is a nickel steel containing approximately 3% nickel and 0.35% carbon; S.A.E. 9255 is a silico-manganese steel containing about 2% of silicon and 0.55% carbon. Some representative examples of alloy steels follow:

S.A.E. 1020—readily forged and machined; can be casehardened; very little increase in strength is provided by heat-treatment.
S.A.E. 1040—readily forged and machined; can be heat-treated; suitable for applications where good physical characteristics are desired.
S.A.E. 1112—carbon steel with about 0.15% sulfur; employed for screw machine products where machineability is the primary requisite.
S.A.E. 2315—3.5% nickel, 0.10 to 0.20% carbon; a "deep" casehardening steel where core ductility is required; recommended for long carbonizing applications and parts of thin section.
S.A.E. 2345—3.5% nickel, oil-hardening steel; used for gears, pins, spindles and other parts requiring great strength and wear-resistant surfaces.
S.A.E. 4140—chrome-molybdenum steel of high strength and high resistance to shock; used for shafts, gears, axles, etc.
S.A.E. 6145—chrome-vanadium steel of high strength and shock-resistance; readily machined when annealed; very responsive to heat-treatment; used for heavy-duty service applications.
S.A.E. 9250—spring steel.

Low-alloy steels, which are at present in the early stages of development, are steels which contain relatively low percentages of the expensive alloying elements but possess a higher yield point and a greater ultimate strength than plain carbon steels. Low-alloy steels are generally *copper-bearing,* and contain from 0.5 to 1.5% copper, with small percentages of manganese and nickel. They are sold under trade names such as *Cro-mansil* and *Corten,* and may be obtained in sheet, structural shape, and tube form at about twice the price of plain carbon steel.

Stainless steels are alloy steels employed principally for their resistance to corrosion. Their cost and corrosion-resistant characteristics vary almost directly with the amount of chromium present. The "18-8" alloy is representative; it contains from 18% to 20% chromium and from 8% to 12% nickel, is malleable and ductile, and may be drawn, formed, welded and soldered. It is extensively employed for food-handling equipment and is not affected by milk products, fruit juices, or most organic acids.

Plain carbon and alloy steels employed for cutting tools will be considered under the head of cutting tool alloys.

18. Non-ferrous metals are generally more expensive per pound than the ferrous metals, and are used only when some characteristic not possessed by iron or steel is essential or desirable in application. Some of these characteristics are: high electrical and heat conductivity, high corrosion resistance, non-magnetic qualities, light weight, and ease of fabrication.

Lead is highly resistant to corrosion, but its strength is so low that it must be supported by a backing or core of some other material whenever it is subjected to stresses of any magnitude. It is extensively employed as a lining for acid tanks, as piping, and as a coating for electrical cable. It is also employed as the principal constituent of many anti-friction bearing metal linings as well as in other alloys.

Zinc is a soft metal that is employed in the pure form as sheet zinc. Its use as a plating material renders steel sheets corrosion-resistant to a certain extent. In alloy form its most important application is in the die-casting industry. One representative die-casting alloy contains 93% zinc, 3% or less of copper, 4% aluminum, and about 0.1% magnesium. This alloy has a tensile strength of from 40,000 psi to 45,000 psi, and is useful because of its low melting point, since it can thereby be readily formed by casting in metal molds.

Copper has high corrosion-resistant qualities and is the best *commercial* conductor of electricity. It is extensively used for tubing, pipes, tanks, and electrical contacts and wiring. It is also extensively used in alloy form as bronze and brass.

A bronze is usually an alloy of copper and tin. Bronzes are commercially important because of their relatively high strength, their ability to resist corrosion, and the ease with which they may be cast and machined. Some important forms are: machine bronze—90% or more copper with tin; manganese bronze (which is really a brass, rather than a bronze)—60% copper and about 40% zinc with manganese to the extent of 0.8% to 4%; and aluminum bronze, containing 90% copper and 10% aluminum, and having a strength equal to mild steel. This alloy is extensively employed for worm gear rims.

A brass is usually an alloy of copper and zinc. Brasses have most of the desirable characteristics of bronzes with the added advantage that they may be drawn and rolled as well as cast. *Standard brass* is an alloy of 65% copper with zinc; *yellow brass* contains 62% copper, 2% to 4% lead, with zinc and traces of tin and iron. Yellow brass is inexpensive, gives excellent castings, and is readily machined. Brass rod is used as stock instead of steel in some instances, for small screws produced on automatic machines. The resulting economy made possible by the increased production and the less frequent tool sharpening and setting offsets the higher

initial cost of the free-cutting brass. Brass is also employed for high-strength die-castings; one representative alloy, *Brasteel,* has a high tensile strength with good fusibility and surface-finish characteristics.

Beryllium copper is an alloy of copper with up to 3% beryllium (an expensive light-weight metal). It has high tensile strength, high resistance to corrosion, and good resistance to wear. *Everdur* is a copper alloy containing 3% silicon and 1% manganese, having an ultimate strength of 90,000 psi in die-pressed part form. It has a high resistance to corrosion and can be welded to steel and non-ferrous metals. *Monel metal* is a *natural* alloy containing 68% nickel and 29% copper, with some iron, manganese, and minor ingredients. The material is mined as ore in the alloyed state. Monel metal is stronger and tougher than mild steel, and is more ductile than a steel of equal strength. The strength of Monel metal castings will average 70,000 psi and the strength of rolled and forged parts will average 100,000 psi. Monel metal can be heat-treated, is resistant to corrosion by most agents, and has high strength at elevated temperatures. It can be welded, brazed, forged, and drawn as readily as steel, and although it is tough, is machineable. It is widely used for marine applications and for food-handling equipment and machinery.

Tin is a corrosion-resistant metal that is used in pure form as an alloying element and as a protective coating for iron and steel plate. About 40% of the annual use of tin in this country is in the form of pure tin-plate or as terne-plate, a lead-tin alloy coating. *Solder,* which is used for joining non-ferrous metals, is a lead-tin alloy containing from 30% to 70% tin, depending upon the characteristics desired in the solder. *Pewter* is another alloy of tin and lead usually containing 80% tin, and is used for ornaments and novelties.

Babbitt metal is a soft material with a low coefficient of friction, and is employed for bearing linings. One type of babbitt employed for aircraft engine bearing linings contains 93% tin, 3.5% antimony, and 3.5% copper. Another type employed for lineshaft bearings contains 15% tin. 25% antimony, and 60% lead. Babbitt metal has little strength, and must therefore be supported by iron or steel shells when it is employed as a bearing liner.

Aluminum is a light-weight metal which is principally employed in alloy form in engineering applications since its strength in the pure state is comparatively low. An aluminum alloy containing about 8% copper is used for sand-molded castings, and is stronger than pure aluminum but possesses less ductility. Zinc alloys of aluminum are used for die-castings, and have greater strength and ductility than copper alloy die-castings, but have less resistance to corrosion and heat. The addition of from 5% to 12% silicon to aluminum furnishes excellent casting qualities in the low silicon range

and effects increased strength and ductility in the higher silicon range. An aluminum alloy containing from 3.25% to 4.25% magnesium furnishes a material that has a tensile strength of about 25,000 psi, is of light weight, and has good ductility, machineability, and resistance to tarnishing.

Duralumin (known in the United States metallurgical literature as 17S) is the basic wrought aluminum alloy. It contains a minimum of 92% aluminum, from 3.5% to 4.5% copper, 0.2% to 0.75% magnesium, and from 0.1% to 0.4% manganese. Duralumin has a tensile strength of about 50,000 psi, attained by an age-hardening process, and is extensively employed in the aircraft industry in plate, tube, rod, and rivet form. When aircraft and automotive engine connecting rod forgings are made of Duralumin, the manganese is in some instances replaced by silicon.

Alclad is the trade name of Duralumin sheets coated with pure aluminum for the purpose of resisting corrosion. Pure aluminum is very corrosion-resistant, its alloys less so.

Magnesium has a lower specific gravity than aluminum and is generally utilized in alloy form. Magnesium alloys are resistant to atmospheric corrosion and to the action of nearly all alkalies and oils, but are attacked by most acids and chlorides. The principal magnesium alloy used in this country is termed Dowmetal, and contains from 85% to 95% magnesium, up to 12% aluminum, and some manganese. Dowmetal may be sand-cast or die-cast, forged, rolled into sheets or plates, and extruded into shapes, tubes and bars. Dowmetal may be welded and machined but is not readily blanked, drawn or pressed. In one Dowmetal alloy, copper and cadmium are added to provide high thermal conductivity.

19. Cutting tool alloys comprise an important sub-division of engineering materials and are both ferrous and non-ferrous in variety. Plain **carbon steels** with a carbon content ranging from 80 to 100 points have for years been employed as cutting tools after subjecting the material to suitable hardening and heat-treating processes. **High-speed steels** are cutting tool alloys that will retain their hardness even when heated to a dull red color, and will therefore cut at much higher speeds, and consequent higher temperatures, than plain carbon steels. One high-speed steel, the 18-4-1 type, contains approximately 0.70% carbon, 18% tungsten, 4% chromium, and 1% vanadium, and is extensively used by manufacturers of twist drills. For broaches and for some turning tools, the 18-4-2, or *double-vanadium* type of high-speed steel has given results superior to the 18-4-1. High-cobalt or cobalt-tungsten steels, which contain from 7.5% to 12% of cobalt in addition to the other elements of high-speed steels, are adapted to heavy cuts and can be subjected to higher cutting temperatures than other high-speed steels. Low-cobalt steels, containing from 4.5% to 5% cobalt, 17

to 18% tungsten, and 0.9% to 1.1% vanadium, have proved very satisfactory for finishing tools requiring tough hard edges.

Stellite is a patented alloy consisting chiefly of cobalt, chromium and tungsten. It is non-corrosive and is not attacked by most acids. It has better red-hardness than high-speed steel but is not as tough. It requires no heat-treatment to develop hardness and cannot be softened by over-heating. It is extensively used for metal cutting, and its resistance to abrasion and corrosion make it applicable for use as a *hard-facing* material, as in turbine blade tips. It costs between $2 and $3 a pound.

Tungsten carbide is a very hard, brittle compound of tungsten and carbon in a cobalt base or matrix, and is employed in machining very hard materials for very high speed cutting, or for application to the contact surfaces of measuring tools to mitigate abrasion and wear. The tungsten

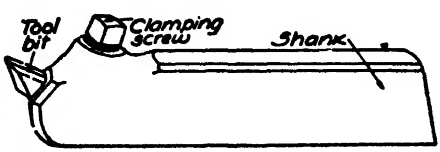


FIG. 1-17. Lathe Tool with Inserted High-speed Steel Tool Bit.

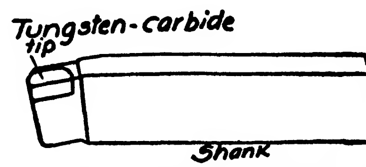


FIG. 1-18. Tungsten-carbide Tipped Lathe Tool with Forged Steel Shank.

carbide is usually made separately in the form of minute particles that are mixed with metallic cobalt powder and pressed to the desired shape. The briquet so formed is then heated in a hydrogen atmosphere to a temperature high enough for the cobalt to sinter the tungsten carbide particles firmly together. The red-hardness far surpasses that of any previous cutting-tool material. Two commercial forms of cemented tungsten carbide are Carboloy and Borium. The material varies in cost from $5 to $12 per ounce.

Tantalum carbide is a cutting alloy that is similar to tungsten carbide but is somewhat softer. It gives better machining effects on some steels than tungsten carbide or Stellite.

Boron carbide is the most recent of the high-speed cutting alloys, and is harder than any of the preceding materials.

In cutting tools made of carbon steel, such as drills and lathe turning tools, the entire tool is generally made of the material. Lathe tools employing high-speed steel or the non-ferrous cutting alloys are generally constructed by employing a small portion of the expensive cutting material, either backed-up or held by a forged steel tool-holder. Stellite and high speed steels are obtainable as "bits" of square section to be held in tool-holder by set screws, as shown in Fig. 1-17 which shows a lathe turning tool. Tungsten and tantalum carbide tool bits are generally brazed in place on

shanks by employing an oxy-acetylene torch and a suitable flux, and cooling by burying in powdered charcoal or graphite. The application of a Carboloy tip to a lathe turning tool is illustrated in Fig. 1-18. In certain cases the tool may simply be hard-faced with the material by use of the oxy-acetylene flame or electric arc and rods or pellets of the desired material. Tipped tools are employed in place of solid tools in order to use as little of the expensive cutting alloy as possible, and to provide a suitable support to avoid fracture from the strain of cutting.

The use of special cutting alloys is constantly increasing, not only because they permit higher production rates and the machining of very much harder steels than can be accomplished with carbon and high-speed steel tools, but also because of the less frequent attention they require as far as sharpening and resetting are concerned.

Diamonds have been used for years as cutting tools, for wire-drawing dies, and for trueing abrasive wheels. Three varieties of industrial diamonds are available: the non-crystalline black diamond or carbon; the imperfect crystalline gem or bort; and the diamond spheroid of radial structure or ballas. Diamond tools are particularly adapted for cutting abrasive materials. Diamond dust is employed for lapping and polishing and fine finishing operations.

20. Non-metals are used in engineering practice for many reasons, among which are their low density, low cost, flexibility, and resistance to the transmission of heat and electricity.

Wood is one of the oldest materials employed in engineering structures and devices. Its strength is high as compared to its density and it may be easily handled and worked, but its applicability is limited by its inflammability and its tendency to rot and warp. Oak is used for structural purposes; maple for hoisting booms, structures and patterns for casting operations; hickory and ash for tool handles; mahogany for small parts such as complicated patterns; balsa in airplane structures; while numerous other woods such as cedar, pine, walnut and birch are extensively employed for utilitarian as well as decorative purposes. Plywood is composed of thin sheets of wood, generally yellow pine, which are glued together with the grain of adjacent sheets at right angles to each other, which minimizes the tendency to warp. The strength and effectiveness of plywood is dependent upon the glue or binder. Plywood for exterior as well as interior use may be obtained commercially.

Glue is a gelatinous substance generally made from fish or bone particles. Waterproof glue is made by adding resin to hot glue and dissolving it in turpentine. The strength of a glued joint increases as the thickness of the glued layer is decreased, and a well-prepared joint will develop a tensile strength of about 700 psi.

Glass is particularly important in the chemical engineering and optical fields. Soda-lime-silica glass is the most common variety. Borosilicate glass has a coefficient of thermal expansion of only one-third that of window glass, and may therefore be subjected to sudden temperature changes with less danger of breakage. Pyrex ovenware and chemical glassware are of this variety. Safety glass may be obtained in two forms: the *wired* variety, in which a wire mesh is imbedded in the glass and holds the fragments together in case of breakage; and *laminated* glass, in which a plastic filler sheet is cemented between two layers of plate glass. The outer plate glass sheets resist normal pressures and abrasive forces, and the filler serves to resist loads which may break the glass and also to retain hazardous fine splinters or sharp pieces in case of accidental breakage. The most important use of laminated glass at the present time is in the automobile industry which uses over seventy million square feet annually. Glass fibers, produced by passing molten glass through fine holes by steam, are employed as insulating material. Glass is now being fabricated in the form of hollow blocks for building purposes.

Leather is extensively used for belting, for clutch facings, for valve and gland packing material, and like uses. Leather belts are manufactured from high-grade beef hides. These hides consist of bundles of fibers with a gelatinous binder which is changed by the tanning solution into an insoluble compound. The best grade of belting leather is cut from a comparatively narrow strip along the back of the hide, and sections are cemented together to form long belt strips.

Cotton is also employed for belting and when so used is generally impregnated with rubber, although it is occasionally employed as an endless woven cotton belt, particularly on very high-speed drives.

Asbestos is a mineral that is of importance in engineering practice because it is both flexible and heat-resistant. It is employed as a covering for steam and other heated pipes, and is combined with cotton for use in brake linings and clutch facings. *Mineral wool* is also employed for heat-insulating purposes, and is made by steam-blasting fusible rock or furnace slag.

Cork is a vegetable product that is employed as a gasket or packing material and as a dampener for noise and vibration in machinery. It is employed in powdered form as an insulator. Its coefficient of friction is high when it is in contact with metal parts, and it is therefore used to a considerable extent for clutch facings, friction wheel materials, and as a covering for pulley rims.

Felt is a cloth made of matted wool fibers by pressing and rolling, and is used for devices which prevent oil leakage from bearings and as an insulating material for eliminating vibration and noise.

Paper is e· .ensively employed in the electrical industry as an insulator for electric ı ıotor coils and windings. Pulleys made of compressed paper are extensively employed on account of their light weight and high coefficient of friction.

Portland cement is the product obtained by pulverizing clinker consisting essentially of calcium silicates, to which no additions have been made subsequent to calcination other than water and/or untreated calcium sulphate. **Mortar** is a mixture of sand, water, and a cementing material. Cement mortar employs Portland cement as the cementing material; lime mortar uses hydrated lime as the cementing material. Mortar is employed principally for brick and stone setting and construction.

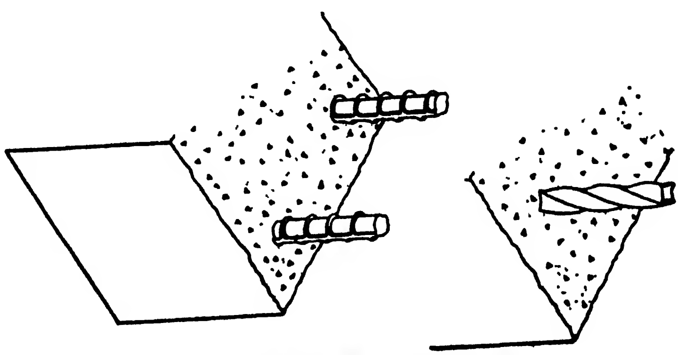


FIG. 1-19. Reinforced Concrete Beams.

Concrete is a mixture of sand and rock or similar inert material, known as fine and coarse aggregates, held together by a cementing material which is usually Portland cement, although asphaltic concrete, employing asphalt as the cementing material is used. Concrete is extensively used for building construction and for bases and foundations for machinery. The following table shows a few commonly-used concrete mixtures:

Mixture	Cement bbls.	Sand cu. yds.	Stone cu. yds.
1-1-2	2.85	0.40	0.80
1-2-4	1.65	0.46	0.93
1-3-5	1.28	0.54	0.90

(One barrel of cement has a volume of about 3.8 cubic feet.)

The compressive strength of carefully-made, properly proportioned concrete is very high, but its tensile strength is negligible, and steel rods or bars are therefore imbedded in the concrete while it is being poured to take care of the tensile stresses. Cold-twisted or deformed bars as illustrated in Fig. 1-19 are generally employed for this purpose.

A floor slab or a beam made with concrete and rods is referred to as a reinforced-concrete slab or beam. The use of steel reinforcing material is not confined in all cases to those portions of the concrete structure undergoing tensile stress; beams are sometimes reinforced with steel rods on the compressive side as well as on the tensile side, and the ends of beams, particularly where they rest on the supporting columns, are reinforced against shear by vertical or angularly placed rods termed *stirrups*. Most concrete construction is effected by building wooden forms to provide molds for the structure required, placing the necessary reinforcing rods in position and then pouring in the freshly-mixed concrete. After several days the wooden forms are stripped from the concrete.

21. A plastic is a material that may be shaped by the application of pressure and retains its shape after the pressure is removed. Strictly speak-

American Hard Rubber Co.

FIG. 1-20. Hard Rubber Acid Pail.

American Hard Rubber Co.

FIG. 1-21. Rubber-lined Pipe.

ing, most engineering materials may be thus classified, but the commercial designation is employed for materials such as rubber—a natural plastic—and synthetic or organic plastics. The term plastic molding refers to the production of commercial parts made of these materials. Plastics are either natural or synthetic and fall into two general classifications.

Thermoplastic materials are those in which heat causes a physical change in the material. The part cannot be removed from the mold while hot, and subsequent heating will change the shape of the finished product.

Thermosetting materials are those in which heat causes a chemical change in the material. Once the chemical reaction is completed, the object is rigid and may be ejected from the mold. Subsequent heating, unless carried to an extreme, will not affect the shape of the finished part.

Soft rubber, composed of raw rubber with about 3% of sulfur, and **hard rubber,** which is raw rubber with from 30% to 50% sulfur, are among the most important of the natural plastics. Rubber can be compounded to resist abrasion, flexing, considerable heat, strong alkalies, and

fairly strong acids, and is unaffected by glycerine, alcohol, and many solvents, although ordinarily rubber is attacked (or swollen) when in contact with the paraffin hydrocarbons such as gasoline. Soft rubber is extensively employed for electrical and vibrational insulation, and is used for bumpers, tires, wire insulation, etc. It is also used for power transmission belting, being applied to woven cotton or cotton cords as a base. Hard rubber is extensively used for piping, valves and fittings; for utensils employed in acid-handling and plating processes, such as pails, funnels and pumps; and, since it can be bonded directly to steel, for linings for pickling tanks. By means of an electro-chemical process, it is possible to deposit rubber over the surface of metal articles of irregular shape, such as hooks, racks, and strainers, and then by subsequent vulcanization obtain a seamless hard or soft rubber coating. This provides a covering for the metal which insulates the article electrically, as well as making it resistant to chemical action.

Strictly speaking, rubber is not a thermoplastic, but it is considered within that classification because of its tendency to return to its original shape when heated.

Shellac is a natural plastic which in its natural state occurs as the excretion of the *lac* insect. The shellac resin itself is thermoplastic, and is used for the manufacture of phonograph discs, for electrical insulation, and to some extent as a *bond* for abrasive wheels.

Celluloid or Pyralin are thermoplastics produced from the intermediate Pyroxylin (cellulose nitrate) by the addition of a plasticiser such as camphor (the cellulose nitrate is not in itself a plastic). These plastics are used for toilet articles, tool handles, safety-glass interlayers, spectacle frames, and for similar applications. The material will soften at relatively low temperatures, which is an advantage in mounting spectacle lenses. The chief disadvantage of these plastics is that the base material is violently flammable.

Cellulose acetate compounds, of which Tenite is one commercial form, are composed of cotton linters and acetic anhydride to form cellulose acetate, which is then transformed to a plastic by some form of plasticiser. This plastic is more stable in light than cellulose nitrate materials and is only slowly flammable. It is extensively used for such applications as fountain-pen barrels, ornaments, and for automotive parts such as knobs and steering wheels which are molded about a metal core. It may be obtained commercially in sheet and rod form. It is tough and is easily molded and colored.

Bakelite is an important thermosetting plastic which is formed from the condensation of phenol and formaldehyde in the presence of a catalyst. The material is generally utilized for molding purposes in powdered form. Bakelite is extensively employed for electrical appliance parts, for automo-

tive parts such as distributor heads, and for novelties. By thinning the powdered material with a solvent, paper or canvas may be impregnated with the solution and, after evaporation of the solvent, bonded together to form laminated rods, sheets and tubes. Textolite, Formica and Micarta are commercial examples of the results of this process.

Urea and formaldehyde, condensed with a catalyst, furnish a plastic that is similar to the phenol-formaldehyde material, but less brittle. The material is translucent and colorable, and is used for household wares and illuminating accessories. Beetle and Plaskon are two commercial forms.

Casein plastics, such as Karolith, a commercial form, are produced from the casein curds of skimmed milk with pigments and dyes added. It is produced in the form of rods and other extruded shapes and has excellent color and appearance. Casein plastics are not water-resistant and tend to become brittle if too dry.

Synthetic rubbers, such as Thiokol, Buna and Neoprene, are employed for tubing, diaphragms, in printing machinery, and for underground cable because of their resistance to attacks by oils, gasoline, light, and ozone. Thiokol is an ethylene-chloride, polysulphide compound which is thermoplastic to some extent. Its odor prevents application for some purposes.

There are many other forms of plastics available today and the list of new commercial compounds in this field is constantly being extended. Reference to commercial literature, trade journals, and the records of engineering and scientific societies should be made before deciding on the selection of materials of this character.

22. Lubricants are employed in engineering practice for two reasons: to diminish friction between the surfaces of machine parts; and to diminish friction between a cutting tool and the material being cut, and at the same time serve to dissipate the heat developed in the operation.

Lubricating oils are employed in rotating and sliding bearings to provide a film that will cause a separation of the moving surfaces, and thereby reduce the frictional resistance of the bearing to that produced by the shearing within the oil film itself. One important consideration in the choice of a suitable lubricant is that it should not absorb oxygen from the air, thus forming a gum, or become rancid and attack the metals with which it is in contact. Another extremely important consideration is that the lubricant shall be sufficiently fluid to penetrate between the moving surfaces, but it should at the same time have sufficient body or viscosity to prevent it from being forced out by the pressure to which it may be subjected.

The term **viscosity** indicates the relative non-fluidity of an oil, and is usually determined with a Saybolt Universal viscosimeter. The viscosity test is performed by noting the time in seconds required for a certain

quantity of the oil to flow through a calibrated orifice under a standard head at a given temperature. The viscosity may therefore be expressed as "255 seconds Saybolt Universal at 130° F." Engine oils have a viscosity of 280-340 seconds for heavy, 175-200 seconds for medium, and 50-150 seconds for light oils, at 100° F.

The **viscosity numbers** adopted by the Society of Automotive Engineers for crank-case oils are arbitrary in character and should be obtained from the S.A.E. Handbook, but they are based on definite Saybolt Universal viscosity readings. For example, S.A.E. 30 crank-case oil, which is employed to a considerable extent as a warm-weather automobile lubricant, has maximum and minimum Saybolt Universal viscosities at 130° F. of 255 and 185, respectively. S.A.E. 10, a cold-weather lubricant, has maximum and minimum viscosities of 120 and 90 at the same temperature.

Pure mineral oil, produced by distillation from crude petroleum, is generally used for machine lubrication. In some applications animal or fatty oils are added to the mineral oils for better lubricating effects.

Greases are lubricating agents of higher viscosity than oils, and consist essentially of a calcium or sodium soap jelly emulsified with mineral oil. Greases are employed where heavy pressures exist, where oil drip from the bearings is undesirable, and where the motion of the contacting surfaces is discontinuous so that it is difficult to maintain a separating film in the bearing. Grease-lubricated bearings have greater frictional characteristics at the beginning of operation, causing a temperature rise which tends to melt the grease and give the effect of an oil-lubricated bearing. Calcium and sodium base greases are most commonly used; sodium base greases have higher melting points than calcium base greases but are not resistant to the action of water. Graphite, either by itself or mixed with grease, is also employed as a lubricant. Gear greases consist of rosin oil, thickened with lime and mixed with mineral oil, with some percentage of water.

Oilless bearings, one form of which is made of maple impregnated with 40% grease, are employed to replace metal bearings where lubrication and maintenance is difficult or likely to be overlooked. Oil-dag is a lubricant that consists of a colloidal suspension of pure deflocculated graphite in acid-free oil, and is sufficiently fine so that it will go through the finest filter paper. Extreme pressure (E. P.) lubricants, such as those employed in automobile rear-end transmissions, are a mixture of black mineral oils and a sulfurized base oil. The base is obtained by heating flowers of sulfur with animal or vegetable oil to effect a loose combination. The effect of the sulfur is to prevent "seizing" of the contact surfaces.

23. Lubricants serve a three-fold purpose **in metal cutting processes.** They act as a lubricant for the chips passing over the cutting edge of the

tool and act as a coolant for the work and the cutting edge of the tool; they keep the cutting temperature at a point where it will neither effect the size of the work nor the hardness of the tool; and, when employed as a continuous stream, they wash away the chips as fast as they are formed. Satisfactory cutting lubricants should possess the property known as *oiliness* and should inhibit rusting or corrosion of the work.

Cutting oils are mixtures of lard, cottonseed or rape-seed oils and mineral oils. Cutting emulsions are usually mixtures of a soluble oil consisting of mineral oil, sodium or potassium base soaps, free fatty acids, and glycerine or alcohol, with a large proportion of water. Paste cutting compounds are usually solid emulsions of mineral oil, sodium or potassium base soaps, and water.

In the selection of a satisfactory cutting lubricant, it is necessary to take into account the cutting speed and depth of cut as well as the nature of the material being machined. Low speeds and shallow cuts require little cooling or lubrication. Low speeds and heavy cuts, particularly when tough metal is being handled, require a lubricant of considerable oiliness. Shallow cuts at high speeds require good coolants; therefore emulsions of soluble and sulfur-base cutting oils are frequently employed. Heavy cuts at high speeds require a lubricant that excels as a coolant as well as a lubricant. Brittle materials such as cast iron are often cut without the use of a lubricant, although emulsions of soluble oil in water are sometimes employed. The highly compounded oils are of value for cutting tough materials. Light sulfur-base oils, or emulsions of soluble oils, are employed for automatic screw machine cutting. Turpentine is sometimes used for machining aluminum (and it may be noted as a matter of interest that this substance is also used when drilling glass). A solution that is valuable for its washing action is one which is composed of 25 pounds of sodium-base soap, 50 pounds of sodium carbonate, and 200 gallons of water.

Cutting lubricants may be applied by hand from a can, by a gravity-feed drop system, or by some medium of forced circulation such as a centrifugal pump. Geared and other positive-pressure pumps are sometimes employed, but great care must be taken to filter effectively the lubricant that is returned from the cutting operations in order to prevent the chips from damaging the pump. In modern plants the chips and scrap metal from machining are collected and subjected to a centrifuging operation to recover a fair proportion of the cutting oil that adheres to them.

24. Numerous types of **surface treatments** are of importance in engineering practice. The principal methods employed in surface treatments are dipping, electro-plating, cementation, and spraying or other forms of painting with or without subsequent baking.

Zinc is used in the least expensive of the coating processes, and is applied either by dipping or by electro-plating. It is used for bulk goods, such as iron sheets, wire mesh, iron and steel pipe, etc. *Galvanized iron* is iron that has been plated with zinc by dipping.

Nickel-plating is one of the oldest of the electro-plating processes and is still extensively used. It will take a high polish but has some tendency to flake and tarnish.

Tin-plating may be accomplished by electrolysis or dipping. Electro-deposition of tin affords better protection than nickel-plating, but it is less resistant to gaseous corrosion. Most tin plating is done by dipping and the annual production of tin-plated products in this country is nearly three million tons per year.

Brass is employed as a plating material for small ferrous parts, particularly for pressed-steel parts, when the non-corrosive brass surface is desired without the high cost of making the entire part of brass.

Cadmium, deposited by electro-plating, has replaced zinc to a considerable extent on shaped parts such as die-castings, and particularly on finished parts where the dimensions of the object must not be materially affected by the plating process. Cadmium deposits well and prevents the spread of rust even if the coating is thin with slight imperfections. It is extensively used on small parts such as nuts, bolts and screws used in the aircraft, automotive, and marine industries.

Chromium-plating is an electro-plating process which not only resists corrosion but also provides a hard abrasion-resisting surface. It has a higher luster than other platings, but does not deposit well on steel unless an underlying nickel base is provided, and will not deposit well in corners and recesses unless the plating electrodes are specially shaped. It may, however, be employed to provide a hard surface on steel parts of fragile form and complicated shape that might be considerably distorted if subjected to the usual heat-treating and hardening processes. Chromium plating is also employed to restore gages and other measuring devices to their original size after they have become useless through wear, by building up sufficient plating to restore their size and then refinishirg them.

Sherardizing is a cementation process in which objects are heated in powdered zinc, which sublimes and penetrates the pores of the surface treated. Sherardizing furnishes a wear-resisting coating for castings and forgings of iron and steel, and is usually employed for small parts.

Russia iron is made by cementation; iron sheets are exposed to the action of hydrocarbon vapors and superheated steam in an air-tight heated chamber.

Parkerizing is a process by which the iron or steel article is dipped into a solution which converts the surface into a salt such as a phosphate or a

chromate. This produces a gray surface on which the intensity of shade is affected to some extent by the previous treatment, such as sand-blasting, tumbling, etc., that the part has received. Processed parts, when dry, may be dipped into a paraffin oil mixture to change the coating color from gray to deep black. The process is primarily for resistance to corrosion.

Bonderizing is a process that is similar to Parkerizing but which results in a surface that is porous, permitting excellent adhesion of paint.

The Chromodine process converts into a chromate the surface of the part treated, and provides excellent protection when the part is apt to be dented or bent.

Electro-granodizing consists of electro-deposition of zinc or cadmium, followed by conversion of the plated surface into a phosphate salt by subsequent dipping.

The Niter Process of blueing steel consists of immersing cleaned and polished parts in a bath of nitrate of potash at a temperature of 600° F., and then cooling and washing in water.

Metal coloring, particularly for brass and copper, may be accomplished by dipping or coating. For example, brass may be given a blue tint by coating with a solution of one part antimony chloride, three parts hydrochloric acid, and twenty parts water. Brass may be given an antique green tint by dipping the part into a solution containing, among other ingredients, chloride of iron and common salt. Brass may be blackened by treating with an arsenious acid solution. After a part has been colored, it should be washed, dried and coated with a colorless lacquer to prevent oxidation or future discoloration.

A temporary colored surface that is extensively used in the machine shop for layout work on cast iron and steel is made by dissolving crystals of blue vitriol (copper sulphate) in water, and applying it by means of a clean cloth to the surface on which lines are to be scribed. The scribed or scratched lines are thus more easily seen than lines scribed directly on iron or steel surfaces. Powdered chalk dissolved in alcohol is employed to give a temporary white coating, and in many instances the surface can be coated satisfactorily by simply rubbing dry chalk over it.

25. Paints and varnishes are important in many engineering applications, particularly in the production of finished parts of metal and other materials.

Paint may be defined as the suspension of a pigment in a vehicle consisting of a drying oil containing a dryer and a thinner in solution. The most important pigments are white lead, white zinc, and titanium oxide. The vehicle generally employed is linseed oil with a volatile compound such as turpentine or petroleum naphtha added as a thinner to bring the paint to the desired viscosity. Tinting colors are added for colored paints.

Varnish differs from paint in that the pigment is replaced by a resin either in true solution or colloidal suspension, and the linseed oil has been polymerized by heat so that its properties are materially different from those of paint oils. The film that is formed by drying varnish is more elastic and resists the action of water better than a paint film. Interior varnishes such as furniture finishing material are made with a minimum amount of oil varying from 6 to 10 gallons per 100 pounds of resin, but varnishes for exterior exposures, especially *spar* varnish for marine purposes, may have an oil content of up to 30 gallons per 100 pounds of resin.

Spirit varnish in its most important form is a colloidal solution of shellac and alcohol. It is employed as a preliminary filler for oil varnishes, and is particularly important because of the rapidity with which it dries. It is often possible to apply a coat of oil varnish to the surface of wood an hour after a coat of shellac has been applied.

An enamel is a compound of a pigment ground in varnish; the resultant film is heavier and glossier than a paint film. Enamels are extensively employed for covering steel parts.

Japan is an enamel employing an asphaltic pigment. The asphaltic nature of the substance permits rapid drying by baking; the japanning process is employed for typewriter and sewing machine frames and similar parts. In many instances several coats are applied, each coat being baked on and carefully rubbed down before the succeeding coat is applied.

A lacquer consists primarily of cellulose nitrate dissolved in alcohol, ether, or other solvents of the ester class, with a non-volatile plasticiser added. Lacquers are used for metal coatings but priming coats of varnish are generally required. Lacquer is employed as a finishing material for automobile bodies and in the manufacture of *artificial leather*, in which cotton fabric is coated with a Pyroxylin solution and then embossed to simulate the grain of genuine leather.

Airplane dope is a lacquer which is applied to preserve, finish, and tauten airplane fabrics. One form of this substance consists of a cellulose nitrate base with a toluene plasticiser and a thinner. Dope is highly volatile and inflammable, and receives its name from the "dopey" feeling it engenders in individuals who are subjected to prolonged exposure to its fumes.

Metallic aluminum in flake form may be incorporated with varnish as a vehicle to serve as a protective under-coat paint for wood and metal. Since aluminum has good reflective characteristics, this paint is extensively used as an exterior covering for such structures as oil tanks, which are exposed to the sun and on which the temperature should be kept as low as feasible.

Paints, varnishes and other protective films of similar nature may be applied by several methods, the most important of which are hand brush-

ing, spraying and dipping. Labor costs are generally highest for hand brushing and lowest for dipping. Drying by means of a limited amount of heat, or baking at higher temperatures, is resorted to if possible to facilitate production and conserve floor space in storage. The ability of the surface film to harden rapidly and satisfactorily in the presence of heat is often an important factor in the selection of a paint or varnish.

There are numerous other means of providing surface protection, such as metal spraying, glass coating, etc., some of which will be considered in the sections dealing with processes. It should be noted, also, that some of the processes, such as carburizing and nitriding, discussed in the heat-treatment of steels, are protective coatings.

26. Heat treatment of metals may be defined as an operation or combination of operations involving the heating and cooling of a metal or alloy in the solid state to effect changes in the structural arrangement of the material, and to insure certain desirable physical characteristics. (The application of heat to facilitate the "working" of the material, as in forging or welding processes, is excluded from the scope of this definition.) The general effect of various processes are given herewith:

Annealing is a process of heating and slow furnace cooling a material in its solid state. It may be employed to remove internal stresses, to reduce hardness, increase ductility, and to effect changes in electrical or magnetic characteristics.

Normalizing is a form of annealing in which metals are heated to a definite temperature, and cooled in still air to remove the effects of any previous heat-treatment and to produce a uniform grain structure before other heat-treating processes are applied to develop desired physical characteristics.

Malleabilizing is an annealing operation for cast irons, whereby most of the combined carbon is transformed to free agglomerated carbon in an iron matrix. Graphitizing is similar to malleabilizing.

Hardening may be considered under three general heads: *work-hardening,* in which material may receive and retain a desirable or undesirable hardness, as in the case of pressed steel, which must often be annealed between drawing or pressing operations to permit easier working; *age-hardening,* notably manifest in the case of duralumin which, if allowed to age for three or four days after heat-treatment, shows a marked increase in strength and hardness; and *hardening* by *heating* and *quenching,* which is employed for iron-base alloys with some minimum carbon content. A fourth form of hardening known as *air-hardening* is manifested in high-speed steels and some of the tungsten alloys which harden when slowly cooled in air.

Quenching is the process of cooling by immersion in ice water, cool water, oil, molten lead, or gases, and is a hardening treatment. When steels are quenched, the carbon present is retained in the material as iron carbide in solid solution. The hardness of a steel is dependent upon the amount of carbon present. The hardening treatment increases the strength and wear resistance of most steels, but reduces the ductility and makes the material more brittle.

Tempering is the process of reheating after quenching, and hardening to some intermediate temperature followed by cooling. The term **drawing** is synonymous with tempering but is not preferred in commercial practice. Tempering restores ductility and reduces brittleness, and results in some decrease in hardness, depending upon the temperature and time of the tempering process.

Carburizing is the process whereby carbon is added to iron-base alloys by heating the metal below its melting point in contact with carbonaceous material. The term **cementation** is preferred commercially.

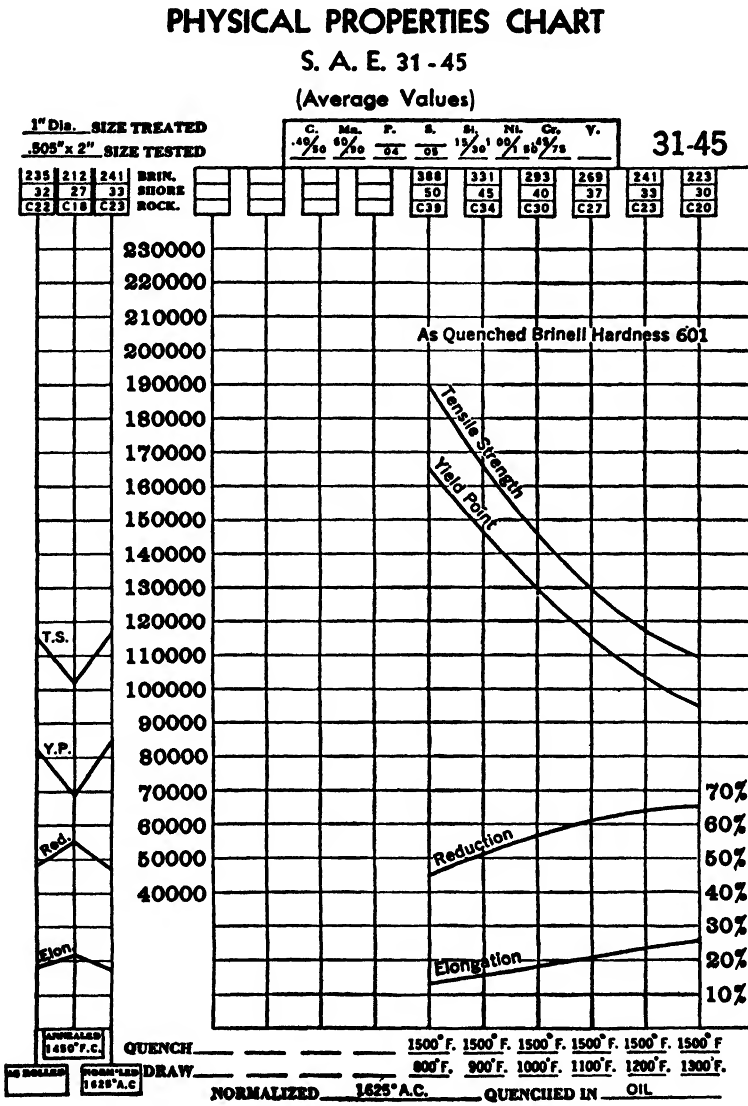
Casehardening is a cementation process with subsequent hardening of a portion or all of the surface of an iron alloy part. This is accomplished by prolonged heating of the part which is protected from the air by packing it in bone char, leather scraps, or charcoal. The outer portion of the part absorbs carbon from the packing material, and displays the characteristics of high-carbon steel when heat-treated, hardened or quenched, while the low carbon steel of the interior of the part remains ductile. The terms **casehardening** and **packhardening** are synonymous.

Cyaniding is a process of adding carbon and nitrogen and subsequently hardening a portion or all of the surface of an iron alloy part by heating it in contact with a molten cyanide salt, such as potassium cyanide or a mixture of potassium ferrocyanide and potassium bichromate, followed by quenching. The process is more rapid than casehardening but results in a much shallower "case" or depth of hardened surface. The process is usually employed for parts that do not require finishing after hardening, in contrast to casehardening which provides sufficient depth to permit grinding after hardening. Casehardened parts are extensively employed both as a substitute for more expensive alloy steels and also where a soft, ductile core and a hardened outer wear-resistant surface are desired.

Colorhardening is a process whereby parts are casehardened to a very shallow depth of case by employing some substance such as leather findings for the carbonaceous material. Vivid color effects on steel may be readily obtained. The process is employed principally for appearance in such tools as wrenches and vise and machine tool cranks.

Nitriding is a surface hardening process employed on some alloy steels, and is accomplished by exposing the steel at a temperature of 950° F. to ammonia fumes, thus hardening the surface without further treatment.

Nitriding, on account of the comparatively low temperature at which it is accomplished, has no appreciable effect on the finish or dimensions of the



Bethlehem Steel Co

Fig. 1-22.

part involved, and may therefore be employed after machining and heat-treatment.

Fig. 1-22 shows a chart of physical characteristics for S.A.E. 3145 steel. This is a chrome-nickel steel with percentages of carbon and alloy elements as indicated by the chemical composition given at the top of the chart. This particular steel is normalized at 1625° F. and heated and quenched at 1500° F. It may then be tempered or drawn at various temperatures as indicated at the bottom of the chart. The drawing temperature determines the physical characteristics of the finished product. For instance, if the steel is drawn at 1000° F., its tensile strength will average about 147,000 psi; the yield point will be about 130,000 psi; the percentage of reduction of cross-sectional area at the ultimate strength is 57%; the elongation at ultimate strength is 19% (thus indicating the degree of ductility); the Brinell hardness number is 293, with corresponding Shore and Rockwell hardness numbers of 40 and *C*30. If drawn at higher temperatures (1100° F., 1200° F., etc.) the strength and hardness decrease, while the percentages of reduction of area and elongation increase, indicating an increase in ductility at the expense of strength and hardness. (Hardness is that taken at the interior and not "skin" or surface hardness.)

CHAPTER 2

ENGINEERING ELEMENTS

27. Lumber is generally sold by the **board foot** or in larger quantities by the 1000 board feet. Some types of stock such as moldings are sold by the linear foot, and others, such as shingles and lath, by the bundle. The unit of measurement of lumber, the **board foot,** is 12" wide, 12" long and 1" thick, based on the rough sawed size. For example, a rough beam 10' long, 12" wide and 2" thick contains 20 board feet. Surfaced lumber is seldom found to be the full dimension as listed. Material listed as 2" × 4" studding is actually sawed to this size in the rough, but when surfaced is only 1⅝" × 3⅝". Surfaced 1" stock is generally about 13/16" in thickness. If wooden flooring that must measure 1" in thickness is specified, it will generally be cut from 1½" material and will therefore take the price of the larger rough stock.

Lumber may be obtained in beam and joist form in sizes such as 2" × 4", 2" × 6", 2" × 12", 4" × 4", etc. Finished flooring such as the tongue and groove flooring shown in Fig. 2-3, ship lap, and other forms of clap-boards and siding material, and several types of moldings such as the quarter-round and the common ogee, can generally be obtained from local supply houses and mills. Wood in cylindrical form, or dowel stock, may be obtained in diameters of ¼", ⅜", ½", etc. Plywood can be obtained in thicknesses of ¼", ⅜", ½", ¾", etc., and is generally sold as 4' × 8', 4' × 10' or 4' × 12' sheets.

Common "cuts" in wood are illustrated in Fig. 2-1. Plough and dado cuts are similar except that the first is cut with, and the second across, the grain of the wood. The center bead is semi-circular; the round is only a portion of the arc of a circle. The flute and the hollow are similar inverse forms.

The joints shown in Fig. 2-2 are commonly employed in joinery. The mortise and pin tenon joint may be made by drilling both pieces to be joined, and inserting a section of dowel stock. This construction is less expensive than the usual mortise and tenon but does not hold the parts as well. The blind mortise and tenon joint is employed where the appearance of the end of the tenon is undesirable.

Although wooden structures are being replaced to a large extent by steel and concrete construction, wood is still extensively employed for buildings, and for falsework in steel erection and other temporary struc-

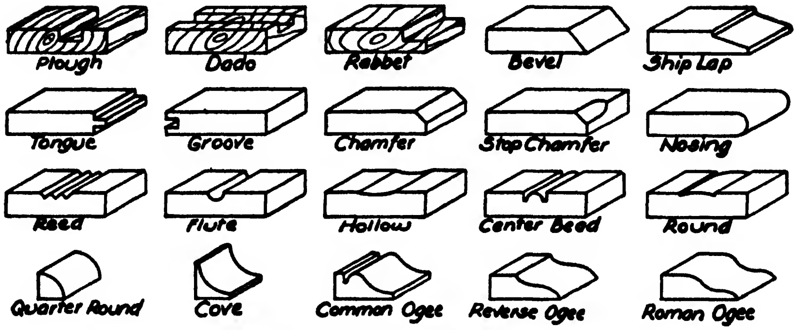


Fig. 2-1. Common Wood "Cuts."

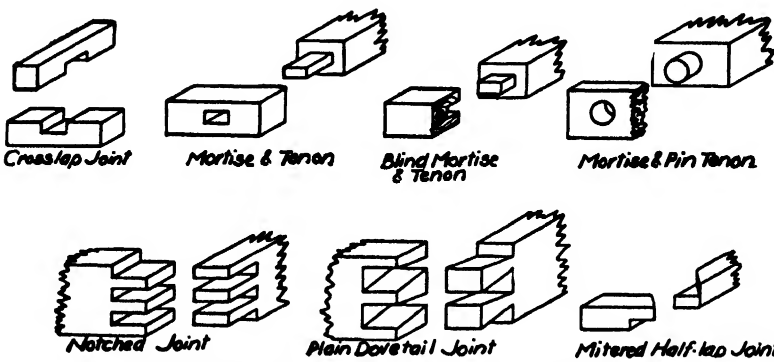


Fig. 2-2. Joints Employed in Joinery and Cabinet-making.

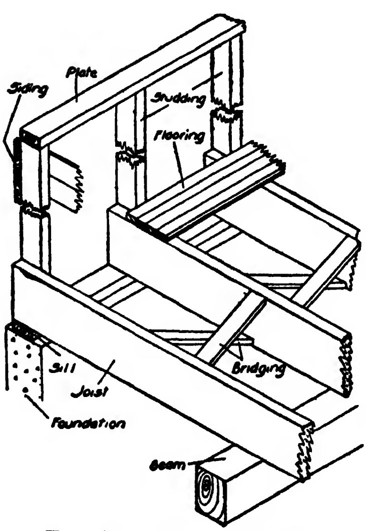


Fig. 2-3. Wood Framing.

tures. Fig. 2-3 shows some of the important elements of a wooden framed structure and Fig. 2-4 indicates some details of timber trusses and beam connections.

28. Fig. 2-8 shows some of the important details of steel construction. Standard **structural sections** may be obtained from any supply house, and are specified in ordering as indicated. A 6″-10 lb. I beam is one that has a depth of 6″ and a weight per foot of length of 10 pounds. An unequal leg angle is shown; equal leg angles are also standard. A few representative special shapes are indicated, which may be obtained on special order, although some

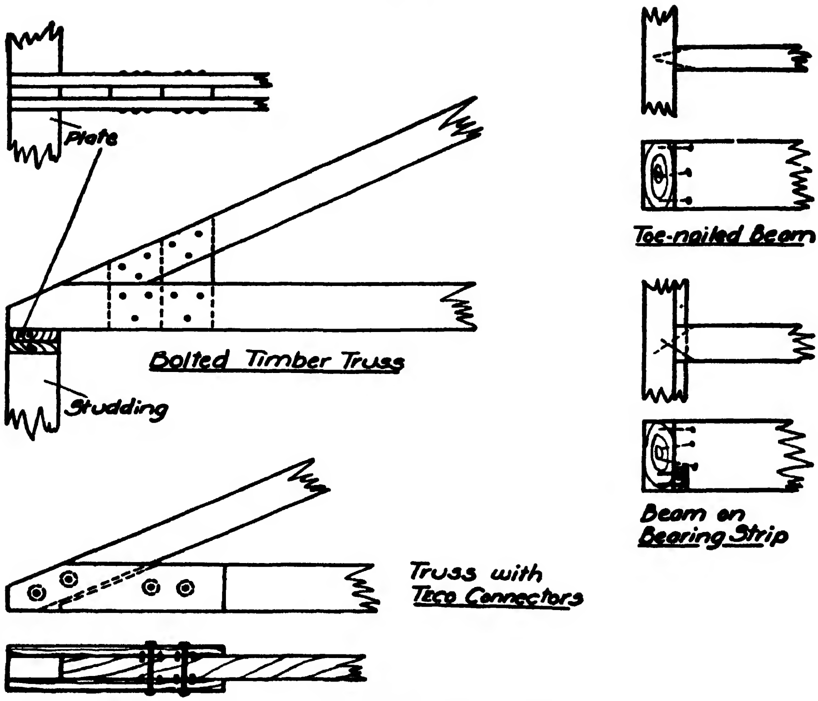


FIG. 2-4. Timber Trusses and Framing.

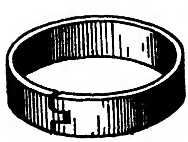


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FIG. 2-5. Split Ring Connector. A Split Ring Teco Connector Is a Smooth Ring of Steel with a Tongue and Grooved Break or "Split" Which Increases Its Load Capacity. Split Rings Transmit Loads When Placed in Pre-cut Grooves in the Faces of Adjoining Timbers.

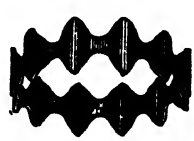

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FIG. 2-6. Toothed Ring Connector. A Toothed-ring Teco Connector Is a Ring of Sixteen Gauge Hot-rolled Steel, Ribbed to Guard Against Lateral Bending, with Sharpened Teeth on Each Edge. These Rings, imbedded Half Their Depth in the Contacting Surfaces of Adjacent Timbers, Transmit Loads from Member to Member.

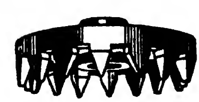

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FIG. 2-7. Teco Shear Plate. Teco Shear-plate Connectors Are Designed to Transmit Loads from Wood to Steel, or Vice-versa.

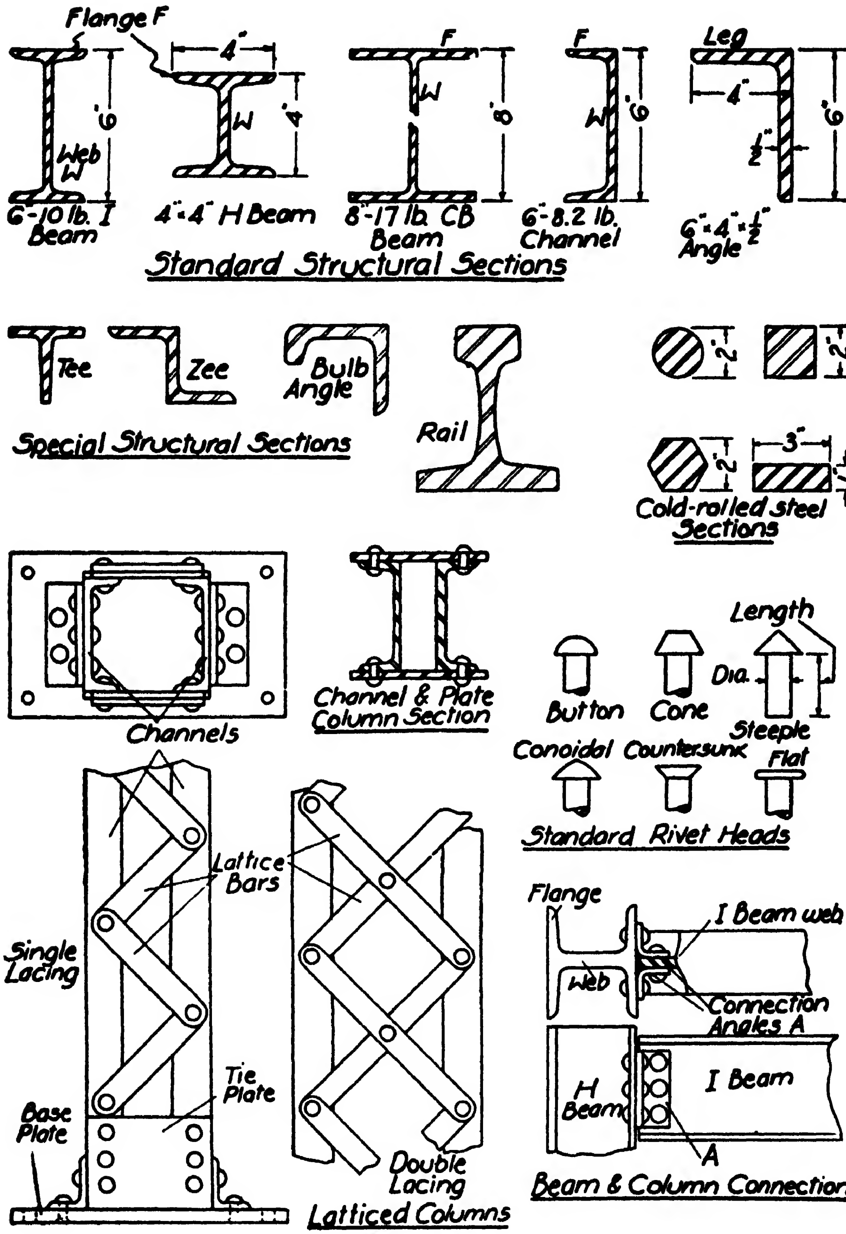


FIG. 2-8. Structural Details.

steel mills carry a limited variety on hand. Structural I-beams are generally used as floor beams and joists; H-beams as columns; and channels, plates and angles are employed for trusses and other fabricated members. Structural aluminum alloy sections are also available.

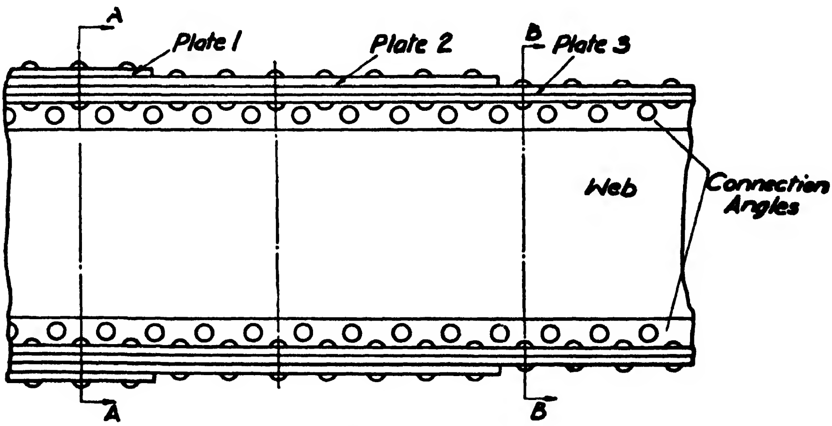


FIG. 2-9. Plate Girder.

When the load on a beam is great, it may be necessary to use a fabricated **plate girder,** illustrated in Fig. 2-9. This girder is really a built-up I beam constructed of plates and angles. It is heavier at the center than at the ends because the stresses are greater. Fig. 2-11 shows a portion of a structural steel **roof truss** employed where the load and span are too great for a single beam.

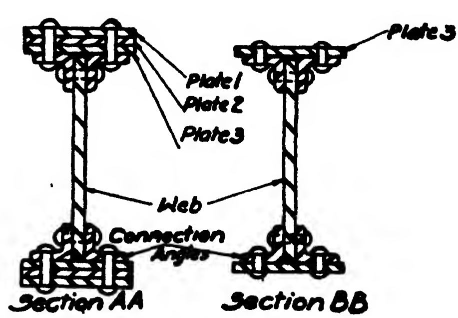


FIG. 2-10. Plate Girder Sections.

High-strength low-alloy steels may also be employed for structural purposes. One manufacturer does this by using rolling-mill strip stock, and rolling the sections cold. The contour of the section is modified to permit cold-rolling, and to provide weight reduction (for consumers will not pay the additional cost of alloy steel if they cannot obtain a corresponding reduction in weight).

Fig. 2-12 shows two deformed zees employed in railroad car construction; Fig. 2-13 shows the cold-formed section that replaces it. The bent over edges of the section of Fig. 2-13 are crimped together. Fig. 2-14

shows a plate and channel column section and Fig. 2-15 indicates its cold-formed replacement.

29. Figs. 2-16 and 2-17 show two forms of **riveted pressure vessels** employed as containers for gases or liquids. The vessel shown in

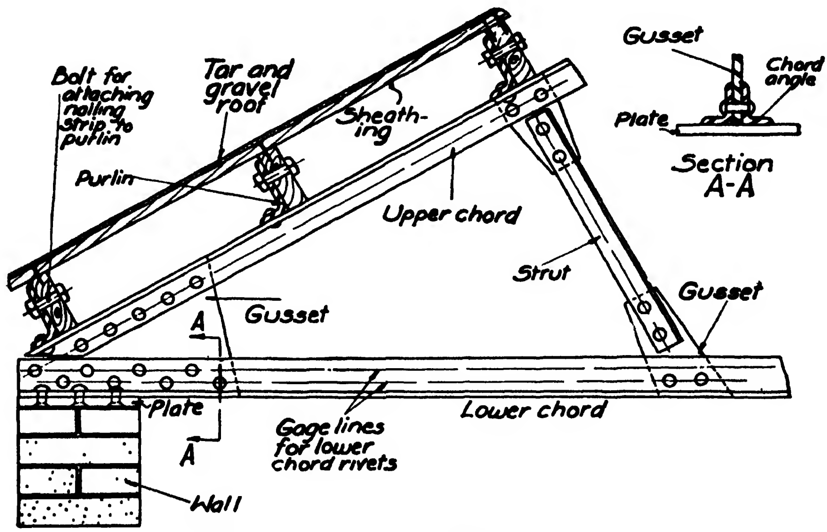


Fig. 2-11. Structural Steel Roof Truss.

Fig. 2-17 may have either a dished head, as indicated, or one of semi-elliptical form. The semi-elliptical head has surfaces which are oblate ellipsoids, in which the depth of the head is equal to about one-fourth the inner diameter. Dished and elliptical heads are stronger than flat heads and do not require the stays as shown in Fig. 2-16.

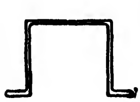


Fig. 2-12. Zee Sections.

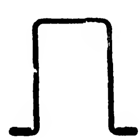


Fig. 2-13. Replacement for Zee Sections.

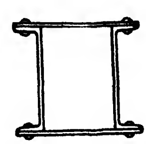


Fig. 2-14. Plate and Channel Column.

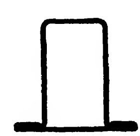


Fig. 2-15. Column replacement.

30. There are two types of **fastenings** used in engineering construction—**permanent** and **removable.** Permanent fastenings are those in which either the fastening or the parts must be destroyed in taking the device apart; removable fastenings are those in which repeated assembly and disassembly is possible without injury to the fastening or the parts.

31. Permanent fastening may be accomplished by **riveting** or **welding.** Welded joints and their application are described in Chapter 15. Representative rivet heads are illustrated in Fig. 2-8. The grip of a rivet is the distance between the flat surfaces underneath the heads after the rivet has been driven in place. Fig. 2-18 illustrates several types of riveted joints as applied to pressure vessels.

Butt joints are superior to lap joints because the pull on the plates in the joints is in the same plane. Staggered riveting is preferred to chain riveting because parallel rows of rivets of the same diameter and pitch can be closer together with equal strength, thus insuring a tighter joint.

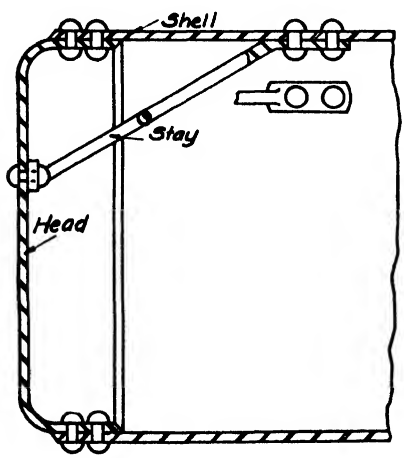


FIG. 2-16. Pressure Vessel with Stayed Flat Head.

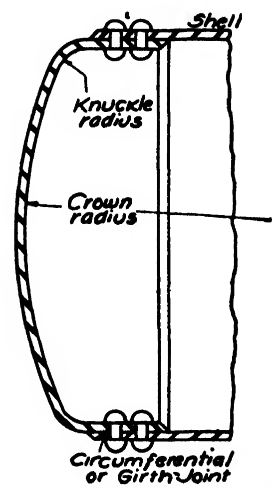


FIG. 2-17. Pressure Vessel with Dished Head.

32. Nails, screws, pins, and keys may be classified as removable fasteners. A screw is a cylindrical part with ridges or threads of helicoidal form on its outer surface, which fit corresponding threads in the hole into which it is inserted. There are two important varieties of screws—those which cut their own mating thread in the hole, and those which fit in a hole independently threaded or tapped. The first type of thread is employed for wood and for self-tapping metal screws; the second for most metal fastening purposes.

33. A number of **screw thread profiles for metal fastening** have been adopted and standardized by the American Standards Association. The sharp V thread is the oldest form, but it is very little used today because of the difficulty of measuring to the sharp crests and because of the likelihood of stress concentration at the sharp roots. It has been replaced to a

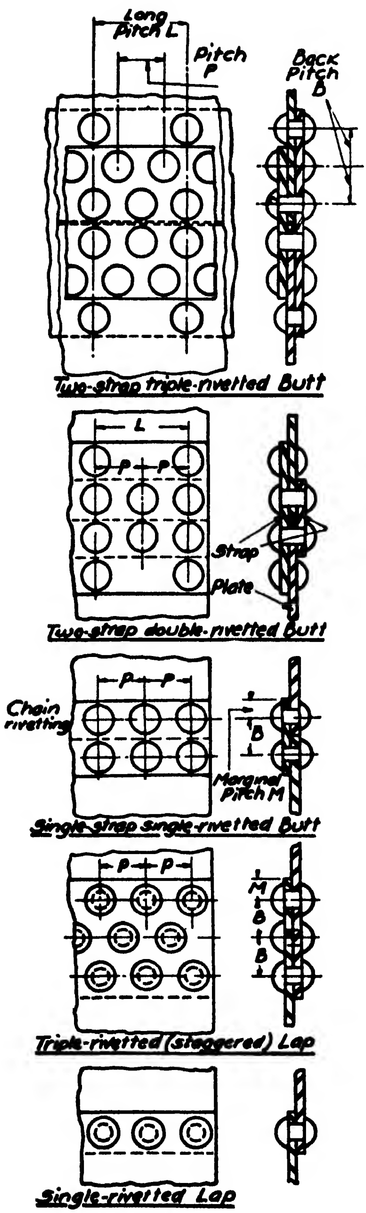


FIG. 2-18. Longitudinal Rivetted Joints for Pressure Vessels.

large extent by the American Standard form which has the same included angle —60°—but is slightly flattened at the crest and root. There are several types of the American Standard thread—the Coarse-thread Series, which is recommended for general use; the Fine-thread Series, which has a smaller pitch than the preceding form and is employed where excessive vibration requires a fine-pitch thread; and several special varieties such as the 8-pitch and 16-pitch Thread Series,

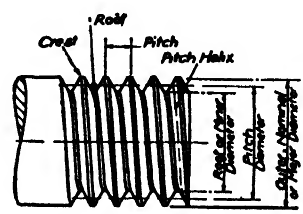


FIG. 2-19. Screw Thread Nomenclature.

which are available in various diameters, with pitches of 1/8″ or 1/16″ respectively. The French and International Standard forms are similar to the American Standard, but are measured in the metric system. The Whitworth form and the British Association Standard are standard thread forms used in Great Britain.

The Knuckle thread is employed principally on screws whose threads are rolled instead of being cut, and is used for carriage and stove bolts. The Electric thread is rolled in sheet metal for electric lamps and sockets, screw caps, and the like. The Harvey Grip thread is used for railroad track bolts and is supplied in two sizes only—3/4″-10 and 7/8″-9.

The Dardelet thread is a self-locking thread having the roots of the ex-

ternal and crests of the internal threads at an angle of 6° to the axis. The nut may be easily screwed on the bolt, but the final tightening causes the conical surfaces to lock in position, and a definite effort is necessary to unscrew the nut, thus preventing accidental loosening caused by vibration.

The Aero-Thread system has been recently developed, and consists of an intermediate insert of spring wire, similar in appearance to a helical compression spring, between the nut or boss and the screw. It is especially useful where high-strength steel bolts are to be fastened in soft alloy parts, since it protects the tapped hole from wear due to inserting and removing the bolt; it also compensates for the difference in expansion of the steel bolt and the light alloy member. High stress concentration under varying temperatures is thereby eliminated. The hole is threaded and the insert screwed in with special tools. For all practical purposes the insert becomes an integral part of the tapped hole, and can only be removed by means of a special extracting tool.

There are three thread forms that are used for **transmitting power.** The Square thread will transmit power without any side thrust, but it is difficult to cut and cannot be conveniently used with split or half-nuts on account of the difficulty of disengagement. The Acme thread is extensively used for transmitting power; it is easier to cut and stronger than the Square thread, and can be readily used with split nuts. The Buttress form has the power transmission qualities of the Square thread and a strength comparable to that of the American Standard. It is employed in jack-screws and for gun breech-locks where power is transmitted in one direction only.

Several other thread forms are illustrated in Fig. 2-20. The wood screw thread, employed in most types of wood and self-tapping screws, permits the screw to cut its own thread as it is inserted in the material. In wood screws the thread area of the screw profile is reduced to permit more strength to be obtained in the internal threads of the weaker wood.

Pipe threads are distinctly different from other thread forms in that the threads are cut on a conical surface, so that the farther the pipe is screwed into the fitting, the tighter the joint becomes. The thread-angle is 60°, and the thread centerline is perpendicular to the pipe axis (not to the conical pitch surface of the thread).

34. Fig. 2-22 shows representative metal screws and bolts. **Cap screws** are commercially available in sizes from 1/4" diameter up. Oval and fillister head cap screws are often preferred to hexagon head cap screws, as the head may be recessed to avoid interference or to facilitate cleaning the part held by the screw. Hex head cap screws can be more tightly fastened, however, than screws with screw-driver slots. The fillister head cap screw with a socket head combines the advantages of the hex head

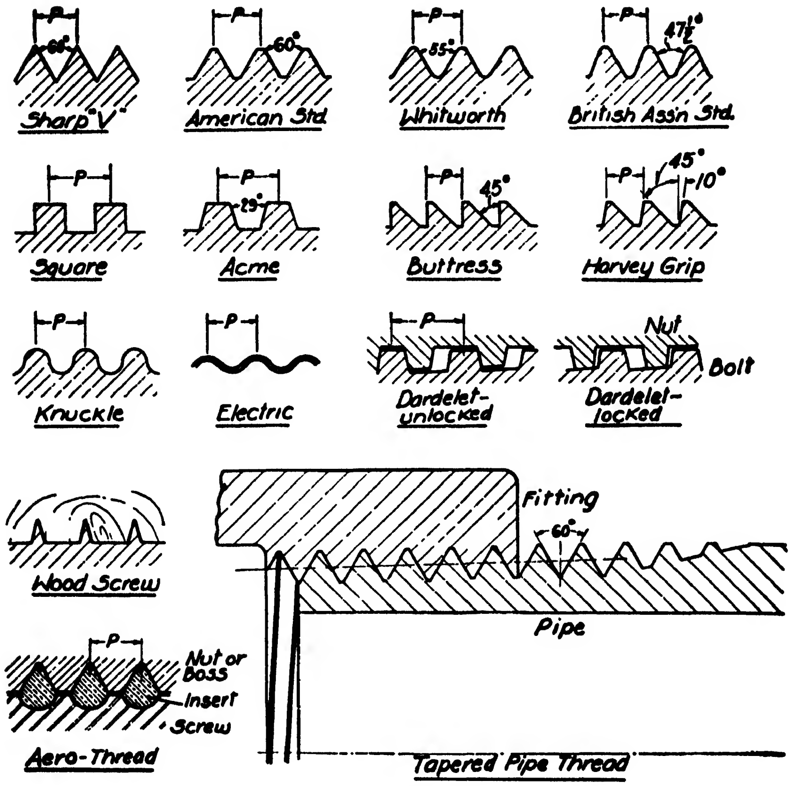


FIG. 2-20. Screw Thread Profiles.

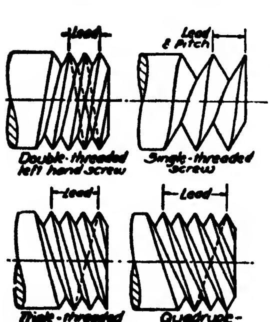


FIG. 2-21. Multiple-threaded Screws.

and the slotted fillister screw. This type is fastened by using a special wrench made of hexagonal bar stock and illustrated in Fig. 16-34. When a screw must be frequently removed, it is often advisable to substitute a stud which may be inserted into the threaded hole, and jammed against the bottom so that it is only necessary to remove the nut, thus avoiding wear on the threads in the hole. (In aluminum alloy castings, the Aero-thread may be employed instead of using a stud.)

Machine screws are similar in appearance to cap screws but have heads of somewhat smaller proportions. The screws vary from .086″ to

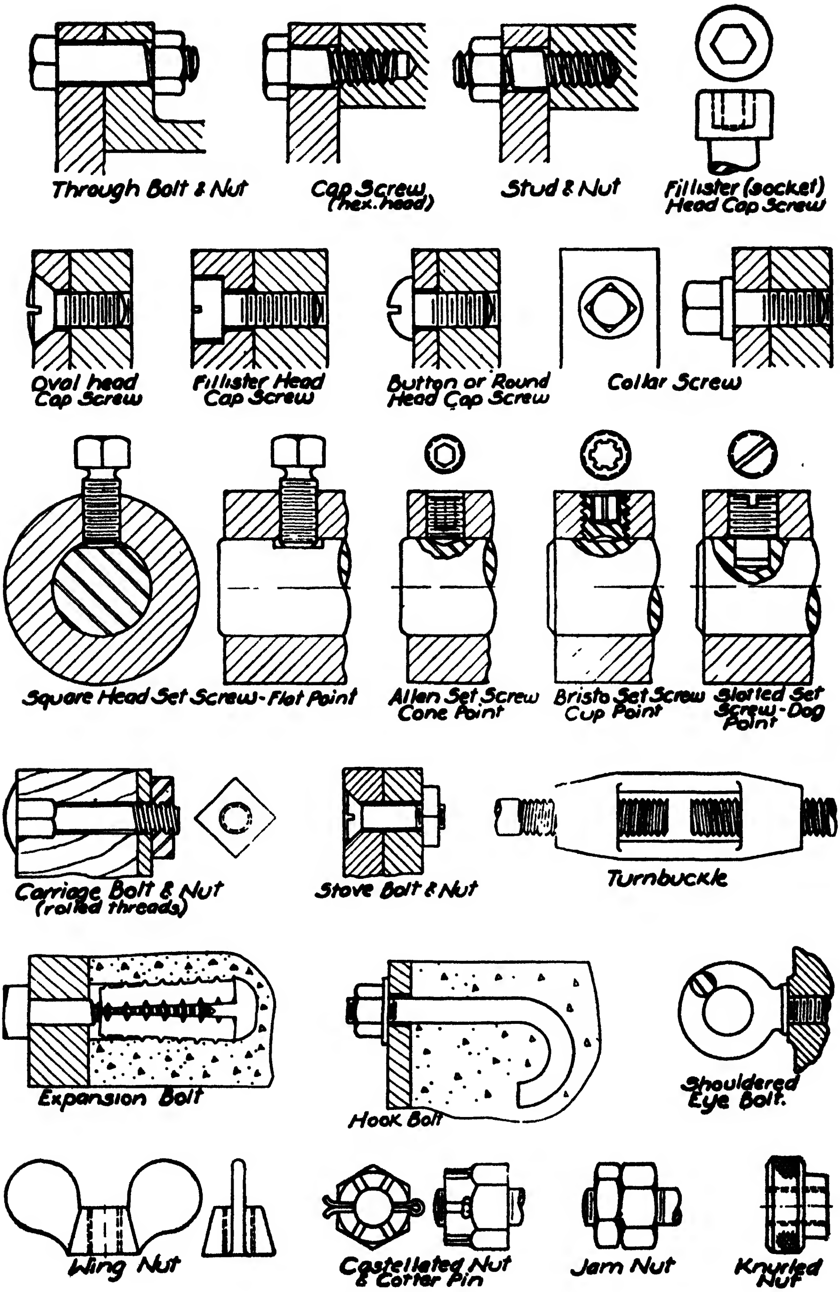


FIG. 2-22. Screwed Fastenings.

.375" in diameter, and the diameter of the smaller sizes is expressed as a number. For instance, a No. 5-44 machine screw has a diameter of .190". Machine screws have American Standard thread forms in both Coarse-thread and Fine-thread series.

Stove bolts are employed for assemblies where precision is of no great importance. They are made with either flat or round head and the screw threads are generally rolled. The square nuts used with them are stamped from common steel. Carriage bolts have a squared portion directly under the head to prevent rotation when the nut is tightened, and are used for fastening wooden parts together or for fastening metal parts to wood.

Expansion and hook bolts are used in semi-permanent fastenings in concrete. Electric motors and medium and light weight machinery are equipped with one or more eyebolts so that they may be readily lifted and moved with an overhead crane. The turnbuckle is a nut which has a right-hand and a left-hand thread, and is used to adjust the length of tie rods and similar devices. The turnbuckle is one of the few instances where a left-hand thread is employed as a fastener.

Set screws differ from cap and machine screws in that they hold by the pressure exerted by their points instead of by the pressure of the head. The Allen, Bristo, and slotted types are safety set screws, since there is no projecting head which may be dangerous if the screw is used on a rotating member. The cone point set screw requires a drilled "spot" on the shaft; the cup point set screw will cut its own seat if the point is hardened (which may cause some difficulty in subsequently removing the hub from the shaft); the dog point set screw is more positive but requires more machining for its application than other types of points. Every set screw shown may be obtained with a variety of points.

Plain **washers,** Fig. 2-23, are placed under the heads of hex head screws and under square and hexagonal nuts. Rough washers are punched from common steel; finished washers may be machined from steel bar stock. Lock washers are used to prevent accidental unscrewing of bolts and nuts, either by exerting additional tension on the threads or by biting into the surfaces in contact. It is possible to obtain button and flat head cap and machine screws with assembled lock washers which cannot drop off, a feature which will be appreciated by anyone who has ever inserted a screw with a loose washer in a comparatively inaccessible place.

The collar screw shown in Fig. 2-22 is used for clamping purposes. The integral collar serves as a washer.

The castellated nut and the jam nut of Fig. 2-22, and the round nut of Fig. 2-23, are examples of means for locking and fixing nuts in place. The castellated nut is held by a cotter pin and has six locking positions per turn; the round nut is locked by a brass key which is forced against the

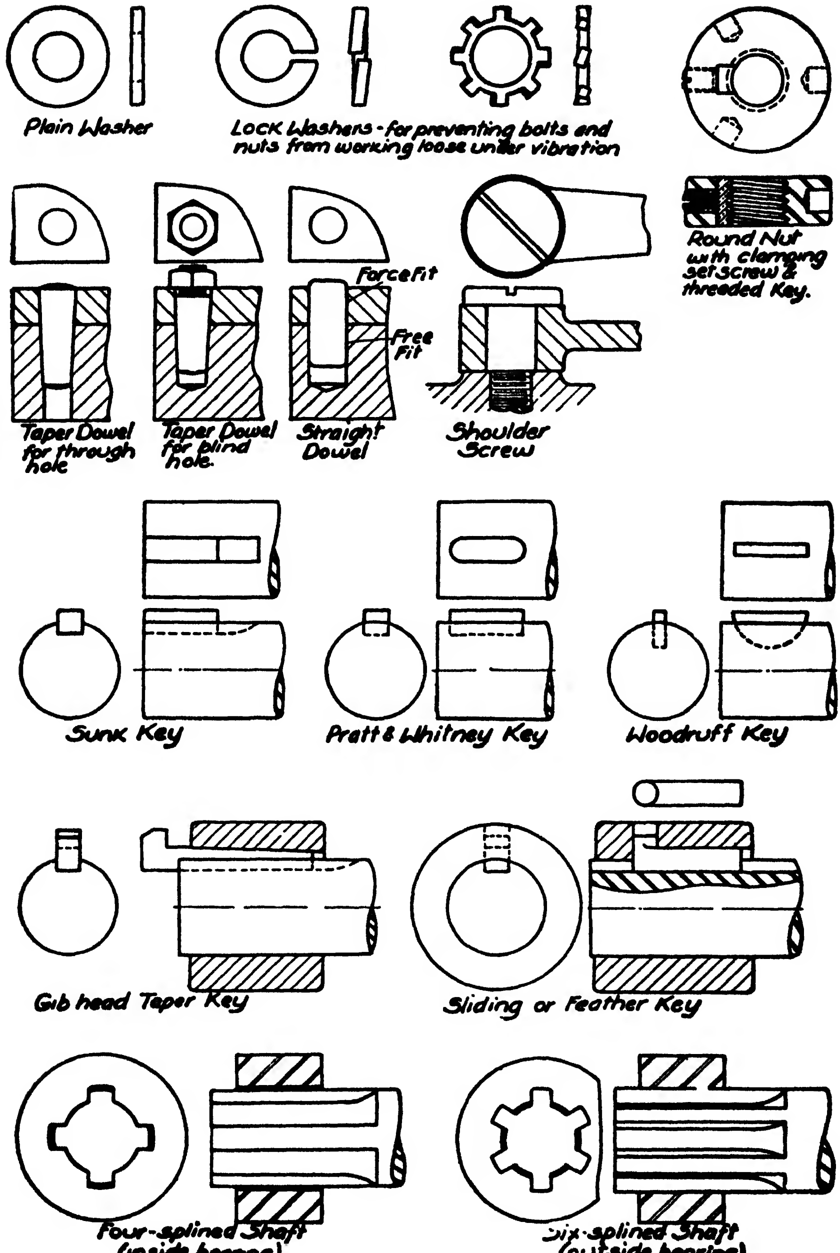


FIG. 2-23. Fastenings.

threads of the screw by a set screw; and the jam nut holds the thin nut in position by being screwed against it. The round nut is adjusted and turned by using a pin spanner, Fig. 16-34, and is preferred to a hexagonal nut if the screw on which it is threaded rotates at any appreciable speed.

Wing and knurled nuts are designed for hand operation. Some forms of fillister head screws are supplied with knurled heads so that they may be readily screwed into place by hand, although the final tightening must be done with a screw driver or wrench.

35. Keys are devices for preventing relative rotation. The gib head taper key will prevent axial as well as rotative motion, since it must be driven into place against the tapered keyway in the hub. The feather key is employed to prevent relative rotation but permits axial motion. It may be demonstrated that the axial force necessary to move a hub along a keyed shaft is twice as great when one key is used, as when two or more keys are used. For this reason, and on account of strength considerations, multi-splined shafts are employed where shafts or hubs must move axially under load. Modern production methods have made it possible to machine both shaft and hole with comparative ease.

Straight and taper **dowels** are employed for light drives, as illustrated in Fig. 3-2. When one machine part is fastened to another, their relative location cannot be fixed by screws because some clearance between the drilled hole and the screw is necessary. In assembly, the two parts are generally fastened together, accurately located, and then fixed by either straight or taper dowel pins, as illustrated in Fig. 2-23. Taper dowels for blind holes should be made with a threaded end at the top so that they may be withdrawn by screwing the nut down.

Shoulder screws are used to provide stationary bearings for oscillating or rotating parts. The screw body should be a free fit in the hole in the part that moves on it, and the length of the shoulder should be slightly greater than the length of the hub so that the screw will not bind, no matter how tightly it is screwed in place.

Shouldered studs, in which a finished washer and nut are substituted for the head of the screw, are employed when removal of the screw for disassembly of the device is undesirable.

36. Fig. 2-24 shows fastening media for wood and metal. There are two principal varieties of wire **nails** used in woodworking—the common nail and the finish nail. The finish nail is employed on finished surfaces where the head of the nail should not be visible. Their small heads allow them to be driven below the surface of the work, and the hole left by the head is then filled with putty or plastic wood. The finish nail does not have as much holding power as the common nail since its head is very much smaller. A brad is a small finish nail ranging in length from ¼″ to 1″.

The size of nails is generally indicated by the term **penny,** which is derived from the weight of 1000 nails; that is, one thousand "eight-penny" nails weigh eight pounds; one thousand "twenty-penny" nails weigh twenty pounds. Both common and finish nails are generally barbed underneath the head to increase their holding power. In some construction work a cement coating is applied to common nails to obtain this effect.

Cut nails are sheared from sheet steel or iron and the heads are formed in automatic machinery. They have more holding power than common or

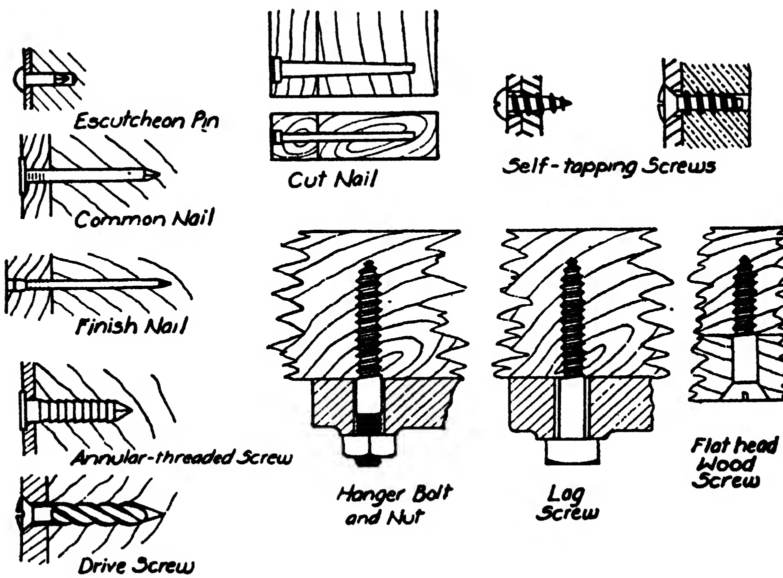


Fig. 2-24. Nails and Self-tapping Screws.

finish nails but must be more carefully driven, particularly with reference to the grain of the wood, in order to avoid splitting. They are usually employed in laying flooring and in panelling.

Escutcheon pins are in effect round head nails used where appearance is important. They are used for attaching name plates and hinges to metal and non-metal parts, and may be made of brass, steel, or aluminum.

Annular-threaded screws and drive screws are employed for permanent assemblies. When used in wood and similar soft materials, they may be directly hammered into place. When used in hard materials, such as hard rubber, bakelite, and other molded plastics, it is necessary to drill a hole somewhat smaller than the screw diameter, thereby making the screw a drive fit. Drive screws can be removed and replaced if necessary.

Wood screws differ from machine screws in that they cut their own thread. Flat-head and round-head screws are extensively used in every phase of woodworking practice. Lag screws are similar to wood screws but have a square head to permit the use of a wrench instead of a screw-driver. When a member must be removed frequently, or even occasionally, a hanger bolt is preferred to a lag screw since it is not necessary to remove the bolt from the wood. The machine screw end on which the nut is threaded will, of course, permit frequent removal.

Self-tapping screws are similar to wood screws. The round-head screw shown serves to fasten two sheet metal plates together. A pilot hole is drilled in one plate, and an anchor hole of the same size as the root

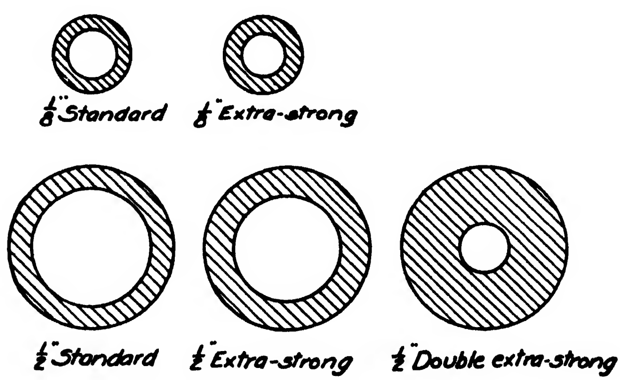


Fig. 2-25. Comparative Pipe Sizes.

diameter of the screw, in the other. The oval-head screw shown serves to fasten a steel plate to a part of soft metal, such as an aluminum or copper alloy. Self-tapping screws may be employed where the screw is only infrequently removed, and where it is desired to save the cost of threading the hole by a separate operation.

37. Pipe is made of a variety of materials. For general purposes, wrought iron and steel pipe with screwed fittings are extensively employed. This type of pipe is specified by the nominal inside diameter which differs from the actual diameter by varying amounts. The three weights of pipe are commonly specified as standard, extra-strong, and double-extra-strong; the increase in wall thickness is obtained by decreasing the inner diameter, and the outer diameter is thus constant for a given nominal diameter. Wrought iron and steel pipe over 12″ in diameter is termed OD pipe, and is specified by giving the outer diameter and the wall thickness.

Cast iron piping is used for underground water and gas mains, for drain service, and for low pressure steam and exhaust pipe. It is specified

by its nominal inside diameter, and its outer diameters vary with the wall thickness required by the service pressure.

Brass, copper, and aluminum pipe are made in steel pipe sizes as well as in tubing sizes. Brass, copper, and aluminum alloy tubes are specified by giving the outer diameter and the wall thickness. Copper tube wall thickness is specified in B. & S. gage; brass, bronze, and aluminum tube walls in B. W.. G. or Stubs gage.

Large fabricated pipe is made of riveted or welded steel plate, and is generally specified by detail drawings.

38. Fittings are used in pipe lines for joining two sections of pipe, for changing the diameter or the direction of flow of the line, or for controlling the flow in the line. Fittings are usually rated as low-pressure,

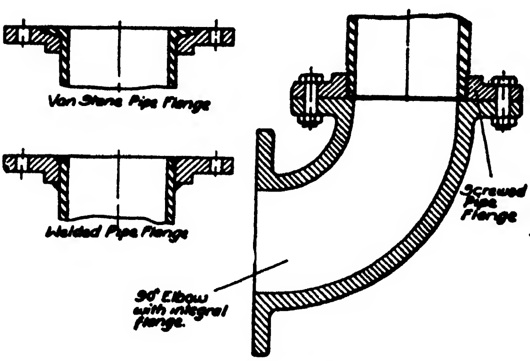


FIG. 2-26. Flanged Fittings.

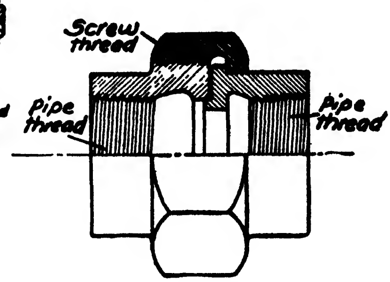


FIG. 2-27. Screwed Union.

standard, extra-heavy, and hydraulic. The low-pressure fitting is rated at 25 lbs. per sq. in. for steam or air; the standard at 125 lbs.; extra heavy at 250 lbs.; and the hydraulic from 300 to 10,000 lbs.

There are two methods of connecting pipe—screwed joints and flanged joints. Flanges are preferred to screwed joints for pipe over 2½″ because larger threads must usually be cut on a machine in the shop, rather than by a hand-operated die or threading tool, and also because it is difficult to handle the larger sizes of pipe wrenches in the field. Screwed joints are made with standard pipe threads, Fig. 2-20, while flanges are attached to the pipe by several methods, a few of which are illustrated in Fig. 2-26.

Two pieces of pipe may be connected by a coupling which consists of a short sleeve with an internal standard pipe thread in each end. One coupling is regularly furnished with every length of pipe. Unions are used where a joint must be taken apart frequently. In many cases unions are a necessity when making the last joint in a line.

Pipe fittings are available in screwed, flanged, and welded types. Welded fittings are described in Chapter 15. Fittings are specified by the nominal

Photo by E. S. Miller, Jr.

FIG. 2-28. Pipe Fittings.

sizes of pipe for which they are threaded, as a ¾″ elbow or a 1¼″ tee. When openings in a fitting differ, the "run" is specified first, followed by

Photo by E. S. Miller, Jr.

FIG. 2-29. Pipe Fittings.

the "outlet," as a 2″ × 2″ × 1½″ tee or a 2″ × 1½″ × 1″ lateral. Short pieces of pipe used to join fittings are termed short nipples. If the pipe is very short and is threaded from either end so that the threads meet, the

fitting is termed a close nipple. Bushings are used to change the size of the line when fittings with different sizes of openings are not available. Plugs or caps are employed to close the end of a line. Blank flanges are used to close flanged fittings or line ends in the larger sizes of pipe.

39. Valves are devices used to control the rate of flow of fluids in a pipe line. **Cocks** are the simplest devices of this character. Cocks or plug valves are sometimes difficult to open and close, and it is often a problem to regulate low rates of flow that necessitate fractional openings. Cocks are therefore usually employed when they are either wide open or completely closed. **Globe valves** are generally used in sizes under 2½″, and should be connected so that the pressure side of the line is above the valve disc, or else excessive force may be required to make the seating leak proof. Globe valves afford minute regulation but offer somewhat more resistance to flow than other types of valves. **Gate valves** have openings parallel to the pipe axis and offer comparatively little resistance to flow. They are universally used in the larger sizes. Check valves are used when unidirectional flow is desired. They are automatic in operation and permit flow in one direction, but prevent it in the other.

Hard rubber pipe and fittings are used where resistance to chemical reaction is required. Valves with hard rubber linings with a soft rubber diaphragm, as well as hard rubber flanged and screwed fittings, are available. Hard rubber lined pipe can be made to withstand the same pressure as iron pipe and fittings, and is employed where temperatures are higher than can be handled in all-hard-rubber piping.

Concrete-lined pipe consisting of a steel or iron pipe with a thin internal layer of concrete is also employed for resistance to corrosion, and is available in standard commercial sizes.

40. Springs are used to absorb energy or shock as in automobile chassis springs; to serve as a source of power as in clocks or watches; and to provide a force to maintain pressure between contacting surfaces as in friction clutches. Fig. 2-37 illustrates representative springs used in engineering practice. Springs with ground ends are generally more satisfactory than those with plain ends; compression springs are more desirable for heavy loads than extension springs, because of the possibility of stress concentration in the loop of the extension spring. Compression springs can, however, be employed for tensile loading. Conical coil springs, if properly designed, may be compressed flat under load. Disc springs represent a recent development that is being extensively employed for heavy loads. Laminated or leaf springs are used in vehicles of various types, although coil springs are now being used in automotive applications. Coil springs may be made of square, rectangular, or round wire.

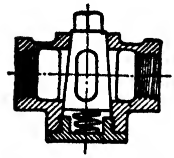


FIG. 2-30. Plug Cock.

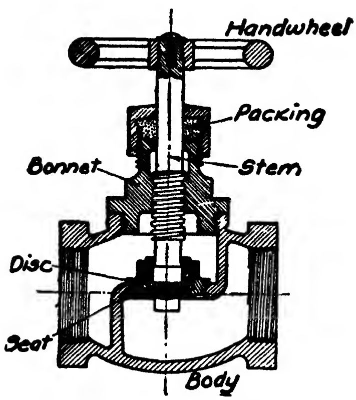


FIG. 2-31. Globe Valve.

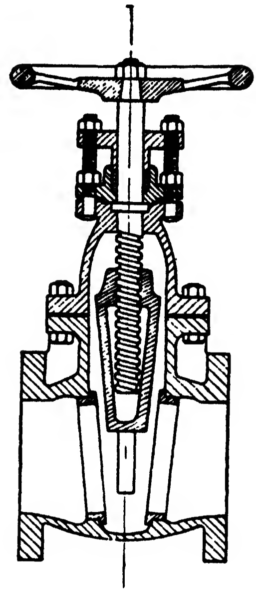


FIG. 2-32. Gate Valve.

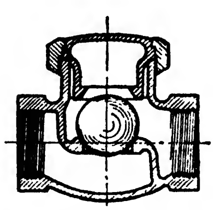


FIG. 2-33. Ball Check Valve.

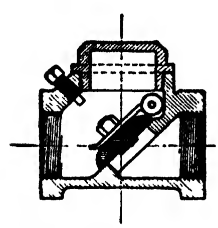


FIG. 2-34. Swing Check Valve.

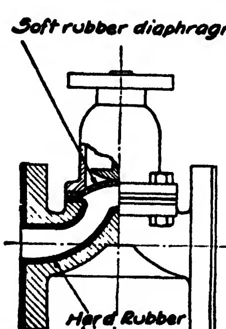


FIG. 2-35. Lined Valve.

American Hard Rubber Co.

FIG. 2-36. Installation of Hard Rubber Pipe and

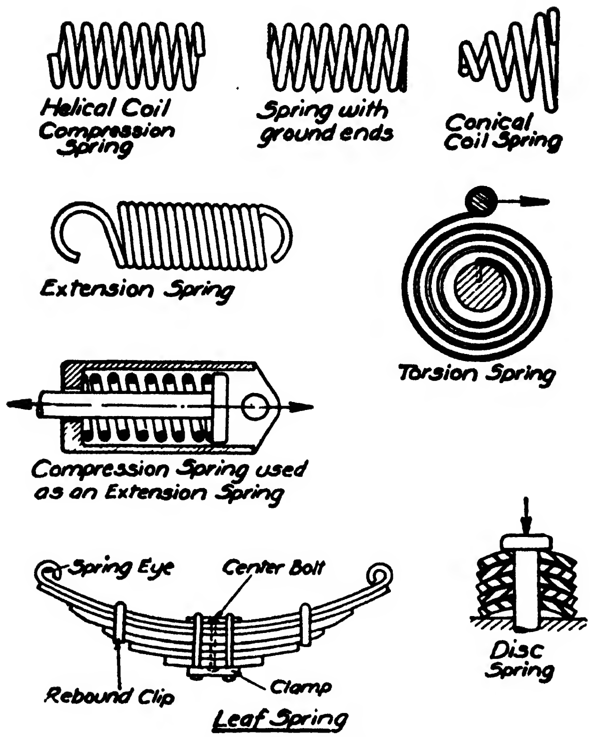


FIG. 2-37. Springs.

Number of Gage	U.S. Standard for Sheets and Plates	American or Brown & Sharpe	Birmingham Wire (BWG) or Stubs Iron Wire	Washburn and Moen	Music Wire	British Imperial Wire (SWG)	Twist Drills	Machine Screws
000	.375	.4096	.425	.3625	.007	.372		
0	.3125	.3249	.340	.3065	.009	.3240		
2	.2656	.2576	.284	.2625	.011	.2760	.2210	.086
4	.2344	.2043	.238	.2253	.013	.2320	.2090	.112
6	.2031	.1620	.203	.1920	.016	.1920	.2040	.138
8	.1719	.1285	.165	.1620	.020	.1600	.1990	.164
10	.1406	.1019	.134	.1350	.024	.1280	.1935	.194

FIG. 2-38. Comparative Table of Gages.

41. Fig. 2-38 shows a few representative decimal sizes of various **gages** used in engineering practice. The United States Standard Gage is the recognized commercial standard for all uncoated sheet and plate iron and steel, and is the legal standard to be used in determining duties and taxes levied by the United States under act of Congress approved March 3, 1893. The American or Brown & Sharpe gage is the recognized standard in the United States for wire and sheet metal of copper and other non-ferrous metals. The Washburn and Moen or American Steel and Wire Company gage is the recognized standard for steel and iron wire, and is also called the U. S. Steel Wire gage. The Birmingham or Stubs Iron Wire gage is nearly obsolete but is still used for specifying the thickness of brass and aluminum tubing, and by the Treasury Department of the United States in connection with the importation of wire The Music Wire gage designated by the American Steel and Wire Company has been adopted as the standard for piano and music wire upon the recommendation of the United States Bureau of Standards. The British Imperial Wire gage is the official standard for Great Britain. The table of Twist Drill sizes is known as the Manufacturers' Standard, since all numbered sizes of twist drills are made in accordance with its specifications. The last column shows a few representative numbered machine screw diameters.

The larger sizes of electrical wiring or conductors are measured in **circular mils.** A circular mil is the area of a circle whose diameter is one mil, or one one-thousandth of an inch. Electrical conductors are specified by using the Brown and Sharpe gage in sizes up to No. 0000, after which they are specified as 250,000 circular mil wire, or 500,000 circular mil wire.

CHAPTER 3

POWER TRANSMISSION ELEMENTS

42. The electric motor is the most convenient medium by which the energy generated by prime movers is applied to the power demands of industry. Practically all machinery used by the manufacturing industries is driven by electric motors, either directly or through the medium of such devices as belting, gears, or chain drives. Every electric motor has two basic elements—the field or excitation element, which in general provides a magnetic field; and the armature, which carries the principal part of the electric power. In some cases, these elements are indistinguishable, in which case they are referred to as the stator or stationary element, and the rotor or rotating element. Under the proper conditions a force is exerted between the two elements, resulting in a relative motion between them if either or both are free to move. A **constant-speed motor** is one whose speed of rotation varies only slightly, if at all, as the load on the motor changes within normal limits. A **varying-speed motor** is one whose speed varies through a comparatively wide range as the load varies between normal limits; there is no sharp line of division between constant- and variable-speed motors. An **adjustable-speed motor** is one whose speed at any given load may be set at any of several values by means of a control device acting on its two basic elements.

There are two types of electric current—**direct current or d.c.,** in which the current flow is constant through a conductor, and **alternating current** or **a.c.**, in which the flow of current reverses periodically. Both d.c. and a.c. motors are available commercially. The principal advantage of d.c. motors is their ease of control; speed and starting torque (the rotative effort exerted by the motor on its connected load) can be closely regulated and widely varied as desired. The principal advantage of the a.c. motor lies in the fact that a.c. power is almost universally used in this country because it can be transmitted for long distances much more economically than d.c. The induction motor, an a.c. machine, is more rugged than other types of motors.

43. There are four principal forms of **direct current motors.** The **separately-excited motor** has its field and armature currents supplied from separate sources. It is a constant-speed motor but its speed is adjustable by a variation of the voltage of either source. **The shunt motor** has both field and armature connected to the same power supply

and, if the supply voltage is substantially constant, is a constant-speed machine very similar in action to the separately-excited motor. The **series-motor** has its field and armature connected in line, or in series, and is a variable-speed motor. The series motor tends to have a constant power output; the speed is approximately inversely proportional to the torque. The no-load speed is ordinarily dangerously high at full voltage, and series motors should not, for this reason, be operated with-

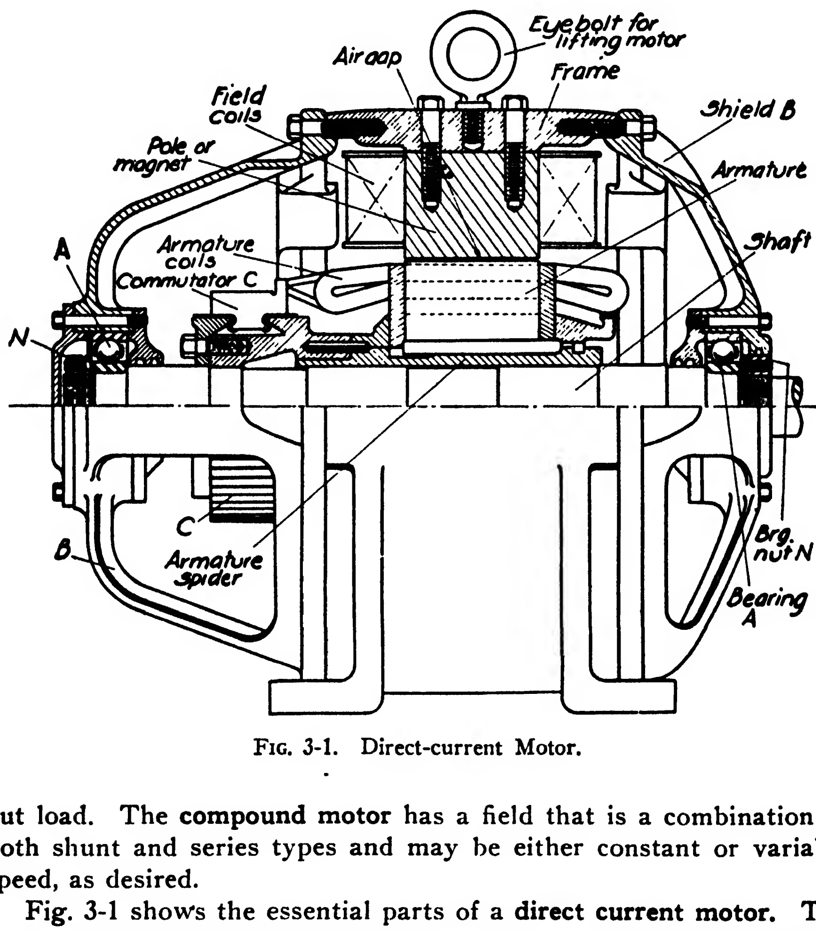


FIG. 3-1. Direct-current Motor.

out load. The **compound motor** has a field that is a combination of both shunt and series types and may be either constant or variable speed, as desired.

Fig. 3-1 shows the essential parts of a **direct current motor.** The field or excitation element is furnished by the frame, the poles or magnets, and the field coils. The armature is composed of steel laminations mounted on a spider or hub which is pressed on the shaft. The armature core carries the armature coils which are connected to the commutator. The commutator consists of copper bars separated by insulating material, and is that part

of the motor through which the armature coils are connected to the motor brushes in such a manner that the machine may use direct current. The shaft rotates in ball bearings *A*, which are housed in the end bells or shields *B*, which in turn are seated in and bolted to the frame. The shaft has an extension at the right, as illustrated, for mounting a pulley, a coupling or a pinion.

44. Most **a.c. motors** are inherently constant-speed machines. The speed is determined by the characteristics of the current supply. Adjustable or varying speeds can only be obtained by expensive construction, greatly decreased efficiency, or comparatively expensive control equipment. **Synchronous motors** are machines that run at an absolutely constant average speed for constant applied frequency. (**Frequency** is the rate of current reversal; a 60 cycle current makes 60 complete alternations per second.) Synchronous motors usually have a stationary a.c. armature or stator, fed from an a.c. current supply, and a rotating d.c. field, or rotor, fed from an attached auxiliary d.c. generator or some other source of d.c. supply.

The current is led into the machine through brushes and a pair of slip rings which replace the commutator of the d.c. machine. As the frequency characteristics are closely regulated on most power systems, synchronous motors are extensively used where constant speed is desirable, as in motor-generator sets. Some synchronous motors have comparatively limited starting torque and the auxiliary equipment required for their successful operation is expensive. By reconnection of the field and armature windings these machines may be made to operate at half or twice their normal speed, but load capacity and efficiency are thereby sacrified.

The **squirrel-cage induction motor** is one of the simplest, cheapest, and most reliable motors built. The stator has an ordinary a.c. winding like that of the synchronous motor and is supplied from an a.c. source. The rotor has no external electrical connections; its winding is a cylindrical cage of bar conductors, all of which are connected together at one end (whence the name, squirrel cage). This motor is of the constant-speed type and the speed is approximately dependent upon the frequency of the current supply. Various combinations of starting torque, efficiency, etc., may be obtained by varying the design of the rotor. Many of the smaller squirrel-cage motors may be started directly from the supply lines, although larger machines require control equipment to permit a reduced starting voltage.

The **wound-rotor induction motor** has a winding on its rotating element similar to that on its stator, the terminals of these windings being connected to outside terminals by slip rings and brushes. The wound-rotor motor displays the characteristics of a squirrel-cage motor in operation

but it has a high starting torque with a much lower starting current than the squirrel-cage machine. It is also used for adjustable speed operation. Because of the extra construction, wound-rotor machines are more expensive than squirrel-cage machines of the same size but they may be employed in instances where starting and reversing are frequent, or in which a larger size squirrel-cage machine would be required to withstand the heating.

Power supply in a.c. circuits may be **single-phase** or **polyphase.** Single-phase power is pulsating, and may be considered as analogous to the operation of a single cylinder engine in which the flywheel returns energy to the cylinder during the compression part of the cycle. A polyphase circuit is somewhat analogous to a multi-cylinder gasoline engine in which the power delivered to the crankshaft is practically constant, since one or more cylinders are firing while others are compressing. In polyphase circuits the total power is constant if the loads are balanced, and these circuits are thus highly desirable for power purposes. Three-phase systems are commonly used for the a.c. motors previously described.

Single-phase motors are extensively used, particularly in applications of small size, because the machines may be connected or plugged into lighting circuits by means of wall outlets, since these circuits are of the single-phase type. A simple single-phase induction motor has no starting torque at all. It must be started by external means, after which it will accelerate in the direction in which it is started and operate much as a polyphase motor would, except at a slightly lower speed. The **capacitor motor** is designed to overcome this lack of starting torque on single phase circuits and has good starting and running characteristics. The so-called **split-phase motor** is also employed for this purpose; it is inferior to the capacitor motor, especially as regards efficiency and starting torque, but its first cost is less. These motors are used principally for small power applications, from a small fraction of a horsepower for the split-phase motor to about one-half horsepower for the capacitor type.

Alternating-current motors with commutators are also employed on single-phase circuits. The **a.c. series motor** is similar to the d.c. series motor. The capacity of these motors vary from a fraction of a horsepower to several hundred horsepower. The **universal motor** is a small, high-speed series motor suitable for use on either a.c. or d.c.; ratings on this type extend to several horsepower but only at very high speeds. The universal motor is widely used in fans and small power tools.

The **repulsion motor** is another adjustable varying-speed type of a.c. commutating motor. The **repulsion-induction motor** is similar to the repulsion motor except that as it comes up to speed it changes over to

simple induction motor characteristics. It has the high starting torque of the repulsion motor and the constant-speed feature of the induction type. Ratings extend up to several horsepower.

Alternating current commutator motors are more expensive to build than simpler induction types but in many cases their speed characteristics and other qualities make their use desirable.

45. A **shaft** is a rotating member transmitting power. An **axle is a** stationary shaft on which pulleys or other members rotate. An axle sometimes rotates, but is then generally subjected to bending stresses only without accompanying torsional stresses. A **spindle** is a machine shaft that drives and supports either a cutting tool or work parts on which machining or other operations are performed. In practice, there are exceptions to these usages; the full-floating type of automobile rear axle carries practically pure torsional stress but is commonly called an axle; and the *Code for the Design of Tranmission Shafting* of the American Society of Mechanical Engineers calls the member a shaft no matter what the type of loading.

Transmission shafting is shafting of uniform diameter, and is generally used for power transmission by means of belting. It may be obtained in diameters 1/16″ under nominal standard sizes. Transmission shafting, for example, can be obtained in diameters varying from 15/16″ to 2 7/16″ by quarter-inch increments, and up to 5 7/16″ by half-inch increments. These sizes were established many years ago when shafting was hot-rolled to a nominal size of 1″ or 1¼″, and then turned 1/16″ smaller in finishing. The old sizes are still maintained for reasons of interchangeability.

Machine shafts and spindles are generally designed and manufactured to suit the requirements of the particular installation, and are therefore made to standard nominal sizes, not necessarily of uniform diameter. Transmission shafting is usually made of cold-rolled steel but almost any desired material may be used for machine shafts and spindles.

46. Bearings are employed to support, guide, and restrain moving elements. They may be classified as bearings for rotating and oscillating elements, and as bearings for reciprocating elements. Bearings for rotating or oscillating elements may be further classified as journal bearings and as anti-friction bearings.

A **journal bearing** is composed of two essential parts, the **journal**, which is the inner cylindrical or conical part and which usually rotates, and the bearing or surrounding shell, which may be stationary, as in the case of lineshaft bearings, or moving, as in a connecting rod bearing. There is considerable sliding action between the outer surface of the journal and the inner surface of the bearing, and the resulting friction is modified by

the presence of a film of lubricating oil. Under the proper conditions of oil viscosity, pressure, and surface speed, the oil is forced between the contacting surfaces to build up a fluid pressure under the load on the bearing, and therefore keeps the surfaces of the two elements apart. Any frictional force that is present is due to the force necessary to shear the oil film, and does not depend upon the materials of the journal and bearing. This condition is referred to as **fluid film lubrication.** It depends to a great extent on the manner in which the lubricant is supplied to the bearing. Continuous oil films are difficult to maintain in slow speed, heavily-loaded rotating bearings, and in oscillating or reciprocating bearings. Such elements are said to be imperfectly lubricated and more or less frequent metal-to-metal contact may be anticipated. In these bearings the type and character of the metal surfaces is of importance. Incidentally, the materials of which perfectly lubricated bearings are made are of importance in design because every journal must start and stop at some time in the bearing operation, and fluid film lubrication is impossible until the moving surfaces have attained certain relative speeds.

In general, unlike materials such as cast iron and hardened steel, babbitt metal and heat-treated steel, or bronze and hardened steel, operate best as bearing and journal materials. Lubricated cast iron surfaces are an exception to this rule, as they operate very satisfactorily after a suitable running-in period, particularly in reciprocating bearings. The member that is most easily replaced is usually made of the softer material.

Bearings may be lubricated in many ways. **Intermittent lubrication** is accomplished by using grease or oil, and the lubricant is usually applied by an operator or through an oil hole, oil cup, or grease cup. **Limited lubrication** insures a continuous supply of a limited quantity of the lubricant, and is effected by a drop feed oil cup which permits a constant supply of oil through an adjustable needle valve or by a pad or wick which presses against the journal as it rotates, and which permits the oil to feed to the surfaces in contact by capillary action. **Continuous lubrication** insures an adequate supply of oil to the bearing surfaces and is effected in numerous ways. Ring and chain oiled bearings have a loose ring or chain resting on the journal, which brings oil from an oil reservoir in the bearing housing to the top of the journal as it rotates. In bath lubrication, the journal is partly or wholly submerged in a pool of oil. Splash lubrication is used on reciprocating mechanisms, as in internal combustion engines where the shaft is enclosed and the reciprocating member can dip into a reservoir of oil at each stroke. Pressure lubrication employs a circulating system where the oil is pumped from a reservoir to the bearing and returns by gravity to the reservoir.

47. The simplest form of **journal bearing** embodies a shaft rotating in a hole in a frame or bracket. If any wear occurs in the bearing, it is necessary to replace the bracket or frame. For this reason, bearing holes are generally supplied with sleeves or bushings so that a comparatively inexpensive replacement is possible. Fig. 3-2 shows a burring or countersinking machine that is used for removing the burrs or rough edges on drilled and reamed holes in manufactured parts. The spindle carries a burring reamer or countersink at its right end, and is driven by a belt and a vee-groove pulley which is fastened to the spindle by a taper pin. The

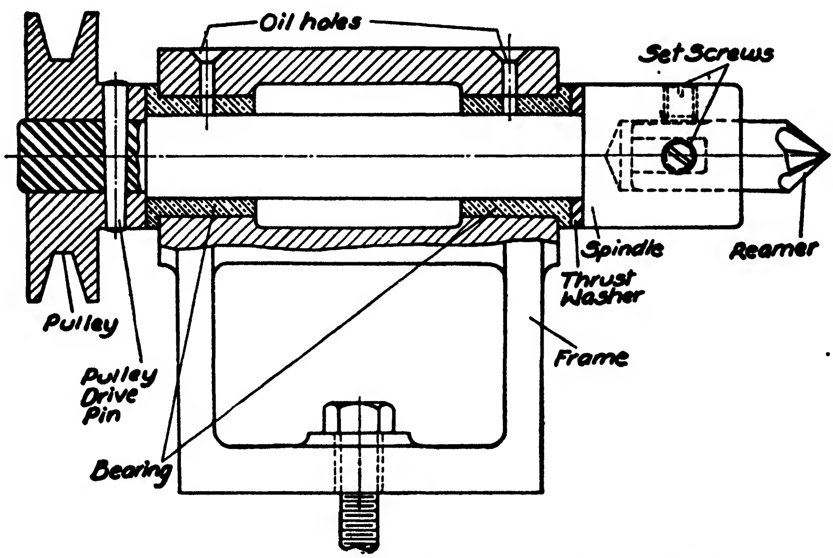


Fig. 3-2. Burring or Countersinking Head—Plain Bearing Design.

spindle rotates in two bronze bearings which are pressed or forced into the frame. The bearing surfaces are lubricated through oil holes in the frame and bearing. The axial thrust caused by the burring operation is carried by two sets of moving surfaces on the thrust washer. (With two sets of contacting thrust surfaces, the relative speeds are lower and the resulting frictional forces are smaller; and, if one pair of surfaces should abrade, the other pair will function satisfactorily.)

Fig. 3-3 shows a split **pillow block** for transmission shafting, which has a babbitt-lined bearing surface. The babbitt metal is cast into the cap and base of the bearing, and is locked in place by recesses or anchors in these members. This bearing is lubricated by a drop-feed oil cup or a grease cup which is screwed into the threaded hole in the cap. Split bearings are more expensive than solid or plain bearings but make it easier to remove

and replace the shaft. Pillow blocks are usually stocked by manufacturers in sizes to fit standard transmission shafting.

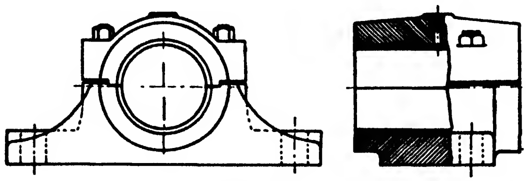


FIG. 3-3. Babbitt-lined Split Pillow Block or Bearing.

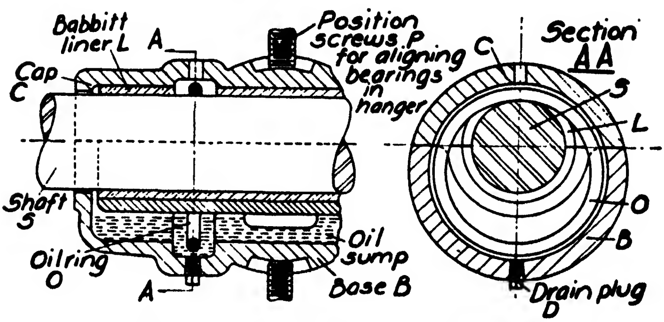


FIG. 3-4. Ring-oiling Hanger Bearing.

Fig. 3-4 shows a split **ring-oiled bearing** for overhead transmission shafting. The entire bearing is supported by two positioning screws P in the **hanger** of Fig. 3-5. The hangers are made of cast iron or pressed steel, and are attached to wooden ceiling joists by through bolts as illustrated, or by lag screws or hanger bolts. Hangers may also be attached to steel ceiling girders by

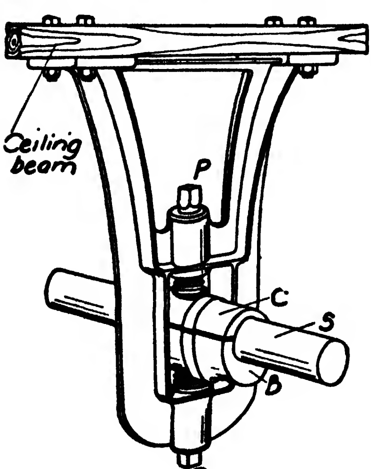


FIG. 3-5. Overhead Bearing Drop Hanger.

Dodge Mfg. Corp.

FIG. 3-6. Wall or Post Hanger.

steel girder clamps and bolts. Wall or post hangers, shown in Fig. 3-6, are attached to walls or vertical columns.

Fig. 3-7 shows a **precision grinding machine head.** The spindle is made of heat-treated steel, and rotates in bronze bearing sleeves *V*. The outer surface of each sleeve is tapered, and fits in a quill *Q*. Adjustment of the sleeves for regulating the bearing clearance, or for rescraping, is effected by turning nuts *M* and *N*; one nut closes the bearing and wedge *W* opens it.

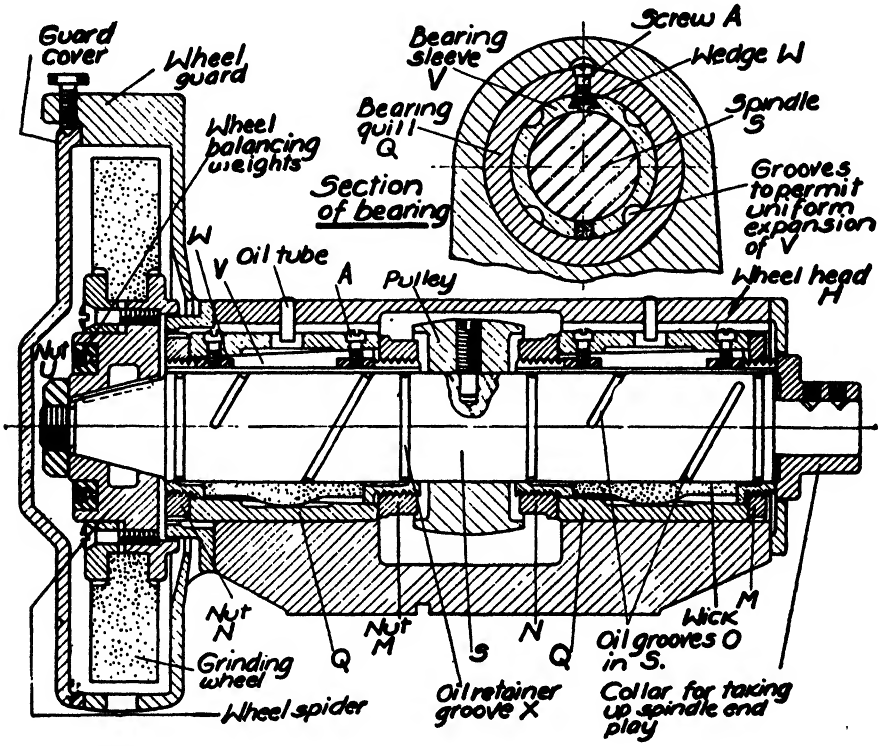


FIG. 3-7. Precision Grinding Machine Spindle.

The spindle has helical oil grooves *O* for distributing the oil obtained from the wick; oil retainer grooves *X* collect the oil and prevent it from running out of the ends of the bearings. The grinding wheel is mounted on a wheel spider which is keyed to the spindle and held on by a nut *U*. This construction is employed so that various grinding wheels may be mounted on separate spiders and readily interchanged. The outer face of the spider has an annular groove in it in which wheel balancing weights may be clamped by expanding them with the set screws shown.

48. Fig. 3-8 illustrates several types of **bearings for reciprocating slides.** Both dovetail and rectangular slides are generally made with some form of **gib** or adjustable strip, so that the slide may be properly fitted and also to enable the slide to be clamped in the guide if desirable. The taper gib, which is adjusted by a double collar screw, is by far the most effective gib but the guide must be planed with one tapered side. The flat gib is the least expensive but does not give as good contact with the slide as the other forms. The V-flat narrow slide is employed on lathes and in installations where the length of the slide is less than the width of the member.

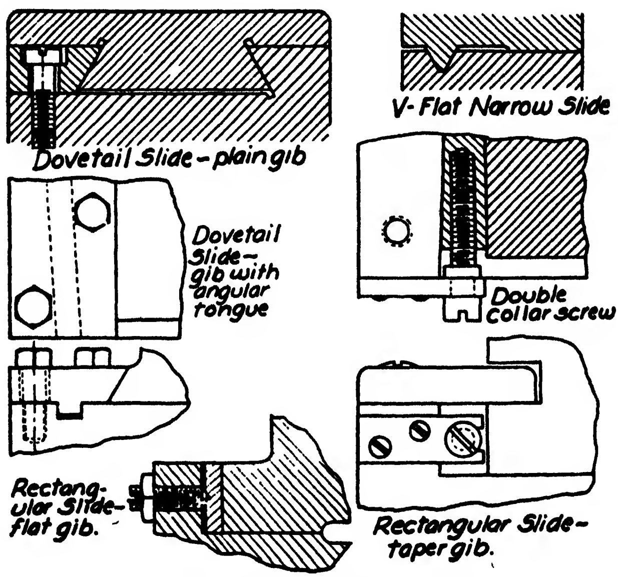


FIG. 3-8. Rectilinear Slides and Gibs.

49. Ball and roller bearings are known as **anti-friction bearings,** and have certain advantages over journal bearings. The actual bearing friction is less than in sliding bearings, and, as it is principally rolling friction, there is little danger of abrasion in machines that are frequently started and stopped under load. Rolling bearings will maintain relatively accurate alignment of parts over long periods of time, can carry heavy momentary overloads without failure, and are very easily lubricated.

Fig. 3-9 illustrates a **single-row radial ball bearing** and housing. The bearing has four elements: the outer race which fits in the housing; the inner race which fits on the shaft; the balls; and the cage or retainer which separates the balls and keeps them properly spaced about the periphery

of the unit. Theoretically there is no reason why the balls could not roll on the shaft and in the housing, but the races are employed to maintain the proper fit and to provide satisfactory surfaces of the proper degree of hardness for the balls to roll on. In the figure, the bearing is resting against a shoulder on the shaft, and is held in position by a lock nut which may be locked at any twenty-fourth of a turn by the washer.

Ball bearings are generally supplied with bores, widths, and outer diameters in millimeters since the bearings were originally used in quantity in Germany, but bearings in standard inch sizes are also available at the present time. Radial ball bearings are made in **three series—light, medium** and **heavy**—and are numbered as follows: 205, 305 and 405, respectively. The bore, in millimeters, between sizes 204 and 213 in the

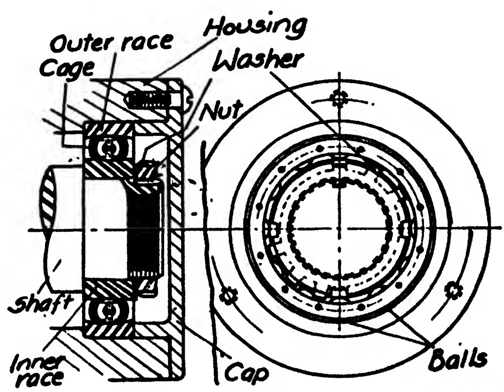


FIG. 3-9. Single-row Radial Ball Bearing Installation with 24-Position Lock Nut.

light series, for example, is five times the last figure in the bearing number. Bearings 205, 305, and 405, for example, all have the same bore but the medium and heavy series bearings, which are used for greater loads than the 205 bearing, have larger outer diameters and greater widths.

Ball bearings cannot be conveniently applied to transmission shafting by the method of mounting shown in Fig. 3-9, and an **adapter-type bearing** is therefore used for this purpose. The inner race of the bearing has a tapered bore which fits over a split sleeve so that, as the bearing is forced along the sleeve, the sleeve is clamped to the shaft and thereby locates the bearing in place. **Double-row ball bearings** have approximately twice the load-carrying capacity of single-row bearings of the same bore, and occupy less space than two single-row bearings.

Fig. 3-11 shows the burring head of Fig. 3-2 redesigned for ball bearing operation. The design is arranged so that all the axial thrust is taken by

the front bearing, and the outer race of the rear bearing is permitted to float axially in the retaining sleeve. The inner races are held in place by

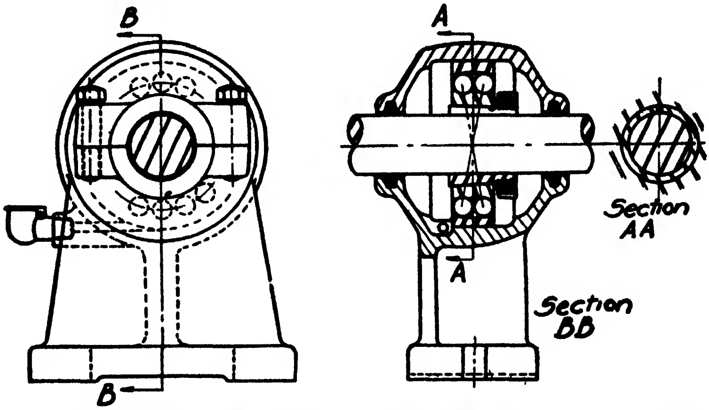


FIG. 3-10. Adapter-type Double-row Ball Bearing and Pillow Block.

a spring-tempered snap ring which is expanded by a screwdriver and snapped into a groove in the spindle. The mountings of Figs. 3-10 and 3-11

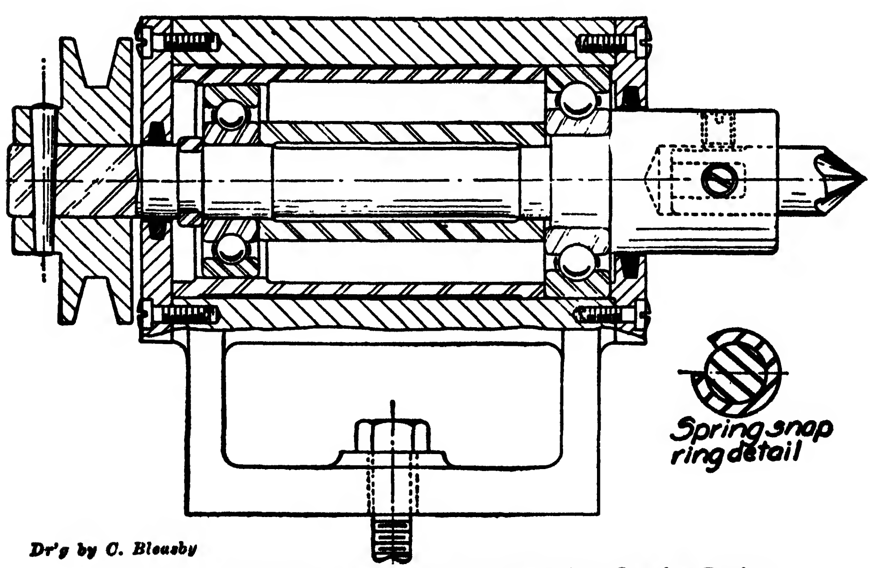


FIG. 3-11. Burring or Countersinking Head—Ball Bearing Design.

illustrate how felt rings in suitable closures are used to keep the lubricant in the housing and to keep dirt and foreign matter out.

Angular-contact ball bearings are designed to take a combination of radial and thrust loads, and should be used in pairs unless the load is pure thrust. This type of bearing is adapted to **preloading,** which consists of placing it under an initial load which is independent of the working load. Preloading tends to reduce the axial deflection under working loads, thus maintaining accurate alignment of the shaft or spindle elements. As illustrated in Fig. 3-10, **self-aligning bearings** are double-row bearings with a spherical surface on the inside of the outer race. This construction allows some deflection in the shaft without causing the bearings to bind.

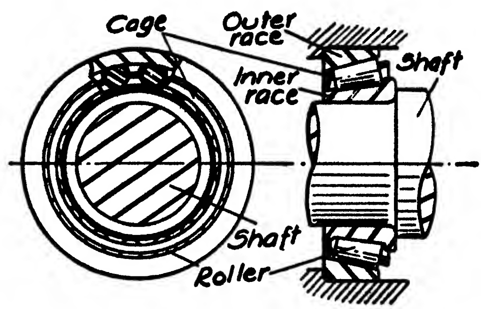
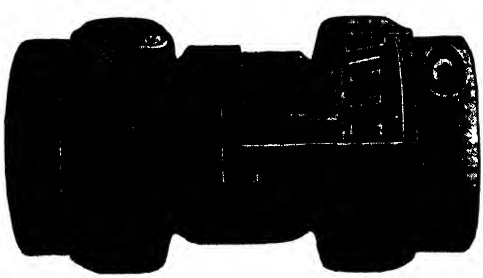


FIG. 3-12. Tapered Roller Bearing.

Roller bearings have a greater load-carrying capacity but develop more friction than ball bearings of similar size. Cylindrical roller bearings are made in three series, similar to ball bearings, and have rollers whose diameters are approximately equal to their length. **Needle bearings** have cylindrical rollers of small diameter and considerable length, and operate without a cage or retainer. They occupy very little diametral space in relation to their load-carrying capacity, and are therefore coming into extensive use in gear mountings, and piston pins in large internal combustion engines.


Dodge Mfg. Corp.
FIG. 3-13. Tapered-roller Hanger Bearing.

Hyatt roller bearings have hollow cylindrical rollers that are made by winding strip steel into helical form. The hollow construction permits greater deflection under load. The bearing is made with inner and outer races but has been successfully applied to transmission shafting where the rollers bear directly on the surface of the shaft.

Tapered roller bearings are extensively used for machine tool and automotive applications, and are capable of taking heavy uni-directional thrust loads in addition to large radial loads. The bearings are used in pairs for two-directional thrust. Fig. 3-13 shows a Dodge-Timken bearing

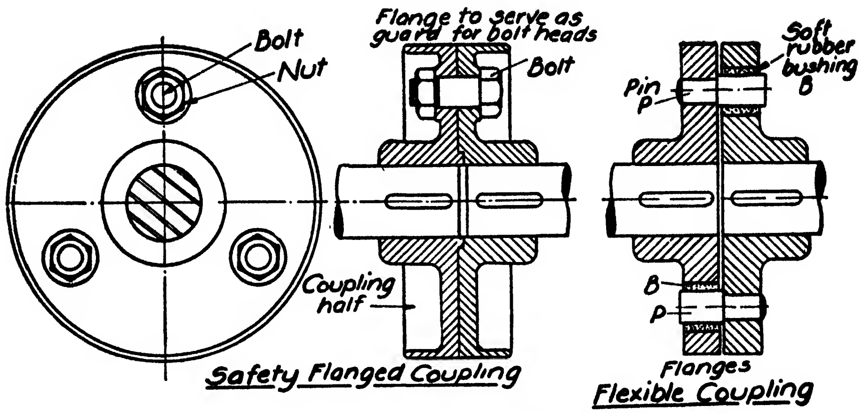
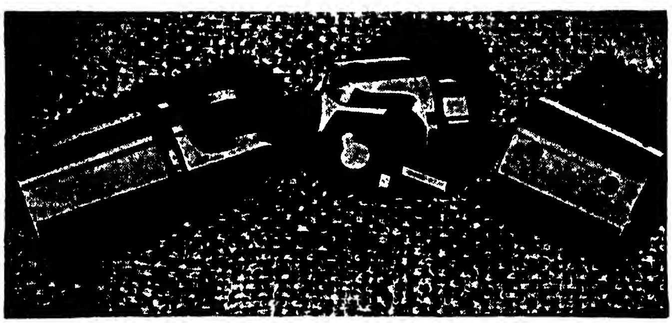
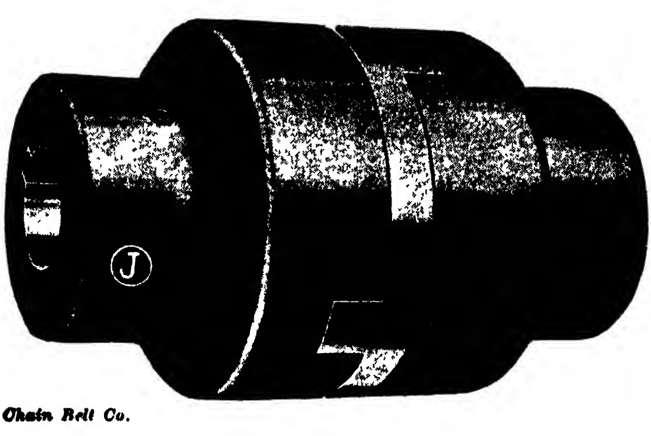


FIG. 3-14. Shaft Couplings.



The Nat'l Automatic Tool Co.

FIG. 3-15. Disassembled Universal Joint.



Chain Belt Co.

FIG. 3-16. Oldham's Coupling.

for the hanger of Fig. 3-5. The roller bearing is mounted on a split sleeve which is clamped to the transmission shaft by the clamp nuts at the ends of the bearing.

In some recently-developed machine tools, rectilinear slides supported by two **"chains" of bearing balls** are used to provide practically frictionless table movement. Ball ways have been applied to cutter grinding machinery and radial drill presses, and will probably find further use in future developments.

50. Couplings and **clutches** are used for direct-connected drives where the motor and the machine shafts are in axial alignment and rotate at the same speed. Couplings are generally considered permanent con-

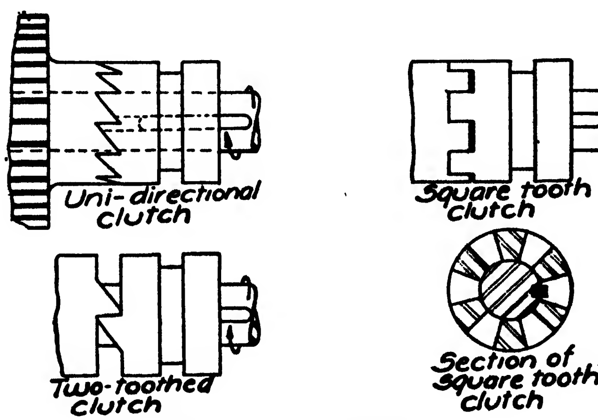


FIG. 3-17. Jaw Clutches.

nectors, but clutches permit instant disengagement or disconnection of the two shafts. There are two principal types of couplings, rigid and flexible. The simplest form of **rigid coupling** is the sleeve coupling illustrated in Fig. 3-19. This coupling consists of a hollow cylinder keyed to both shafts and held in axial position by set screws. Fig. 3-14 illustrates a flanged coupling which is used for heavy power transmission at low speeds. One coupling half is generally made with a projection which fits in a cylindrical recess in the other half to secure accurate alignment. The coupling bolts should be carefully fitted so that each bolt will carry its proportionate share of the load.

Universal joints are rigid couplings that connect shafts whose axes will intersect if prolonged. The coupling shown in Fig. 3-15 consists of two sleeves which fit on the shafts to be connected, and to which they are held by keys and set screws. A two-part fork fits in each sleeve, and a central block with four projecting pins is carried between the "tines" of

the forks. (The application of this coupling may be seen in Chapter 21; another universal joint application is shown in Chapter 13.) **The Oldham's coupling** is a rigid coupling that connects two shafts whose axes are parallel and a short distance apart, and consists of two coupling halves

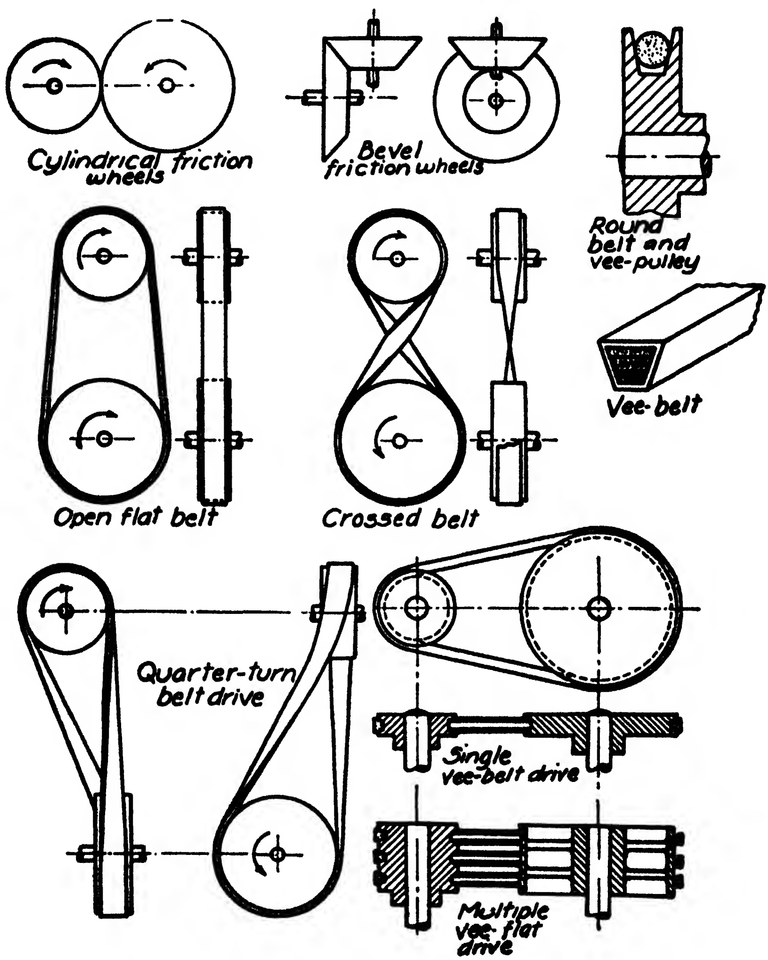


FIG. 3-18. Belt Drives.

which fit the shafts, and a central member with perpendicular tongues that engage slots in the halves. In the position shown in the illustration, the left half of the coupling can move from front to back, and the right half up or down. This combined action takes care of the non-coincident alignment of the shaft axes.

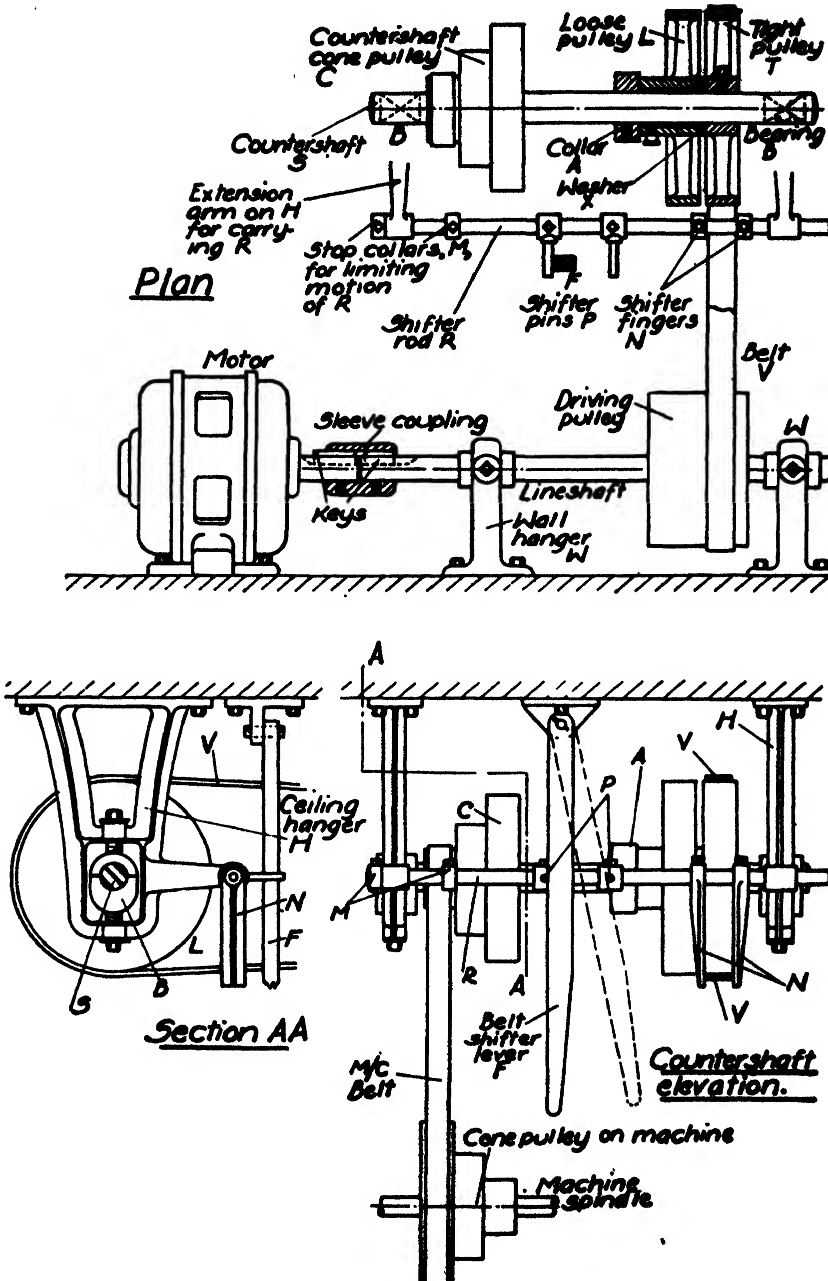


FIG. 3-19. Tight and Loose Pulley Countershaft Drive.

Perfect shaft alignment is practically impossible to secure in machine building and installation, and rigid couplings are therefore likely to cause bearing trouble and possible shaft failure. **Flexible couplings** are used to correct the effects of slight misalignment and to absorb some shock which may appear in one of the shafts. Fig. 3-14 illustrates a flexible coupling in which alternate pins in each half are seated in soft rubber bushings in the other half. This construction permits some axial misalignment, and also takes care of starting shock. Another type of flexible coupling is similar to the flanged coupling of Fig. 3-14 but pins composed of thin steel laminations are substituted for the solid bolts. The pins are relatively flexible, and will permit some angular, as well as axial, displacement.

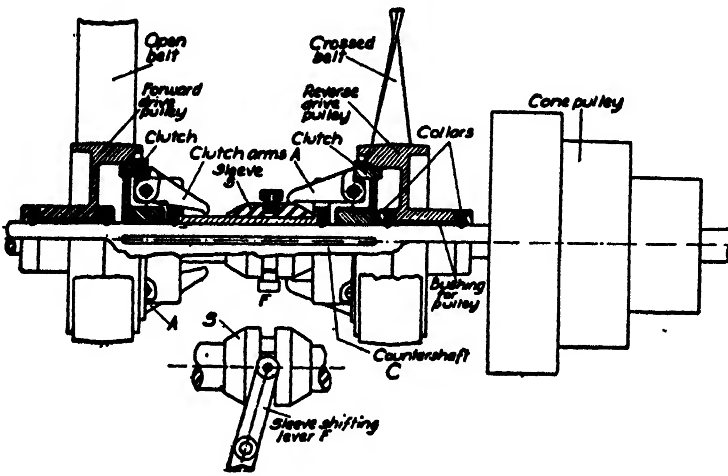


FIG. 3-20. Reversing Drive Counter-shaft.

51. There are two principal types of clutches, positive and friction clutches. **Jaw clutches** are slow-speed positive clutches, and are illustrated in Fig. 3-17. The square-toothed clutch can transmit motion in either direction; the other two can transmit motion only as indicated. The right hand or sliding end of the clutch is keyed to the shaft and rotates with it. The clutch contact faces are usually made at a slight angle—about 3° or 4°—to the shaft axis, as illustrated in the two-tooth clutch, to facilitate disengagement. The square-toothed clutch is very difficult to engage and disengage under load, and is principally used for handwheels on slowly-rotating shafts. The two-toothed clutch is comparatively easy to engage and disengage but will transmit considerable shock if engaged under load.

The cone clutch illustrated in Fig. 3-20 is an example of a **friction clutch** that is used for lineshafting. Cone clutches were used extensively on automobiles in the past but have been entirely replaced by disc

clutches on present-day pleasure cars and trucks. Disc clutches are also used for machine tool and lineshaft power transmission. In the clutch shown in Fig. 3-20, each pulley rotates freely on the shaft when the sleeve S is in a central position between the clutches which are keyed to the shaft, but are free to move axially. (Springs between the inner collars and the clutches prevent involuntary engagement.) When the sleeve moves to the right, as illustrated, the clutch arms A force the clutch into the clutch face in the pulley, and the frictional force between these surfaces causes the pulley to rotate the shaft C. The face of the clutch is often covered with a material such as asbestos or leather to increase the frictional effect, and to prevent abrasion of the metal surfaces. Friction clutches are non-positive but will permit engagement without shock between a stationary and a rotating member, or between members rotating at different speeds.

52. Power transmission between non-coincident shafts may be effected by two media, **positive and non-positive drives.** Each of these classifications may be further divided into drives that connect adjacent shafts, and drives in which the shafts are comparatively far apart. Positive drives offer exact speed ratios and are often used for transmitting heavy loads in limited space; non-positive drives are comparatively noiseless, transmit little shock, and are often inexpensive to install and maintain.

53. **Friction gearing** is used for light load transmission between parallel shafts or between shafts with intersecting axes. If the cylindrical friction wheels shown in Fig. 3-18 are assumed to operate without slip, the surface speed of both wheels must be equal. The velocity ratio of a pair of wheels is therefore inversely proportional to their diameters, or, if a 4″ wheel rotating at 300 r.p.m. drives a 5″ wheel, the larger wheel will rotate at 240 r.p.m. In friction wheel drives, the driven wheel should be made of the harder material for if slip occurs, the softer driving wheel will wear uniformly about its periphery, and will not cut grooves into the surface of the driven wheel. Driving wheels may be made of leather, paper, or fiber; **driven wheels** are generally made of cast iron or aluminum.

When the center distance between the axes of parallel shafts is comparatively large, the use of friction wheels requires too much space and the wheels are too expensive, and **flexible connectors** or belts are generally used. Flat belts are generally made of leather; although folded canvas in "plies" impregnated with rubber or with balata gum (a substance obtained from South America) are sometimes used. **Flat leather belts** are made of oak-tanned or chrome-tanned leather strips cemented together to obtain the required length and thickness. Single leather belts are about 5/16″ thick; double and triple belts are composed of two or three single plies, and are ⅝″ and ⅞″ thick. Belts may be endless, with cemented joints, or they may be joined or laced with wire, rawhide lace, or metal hooks.

Open and crossed belt drives are used for power transmission between parallel shafts; quarter-turn belts may be used when the shaft axes are not parallel. In order for a belt to stay on a pulley, the approaching side of the belt must approach the pulley perpendicular to the axis of rotation of the pulley. By this rule, it may be seen that the quarter-turn belt of Fig. 3-18 will operate satisfactorily for the indicated directions of rotation but will not stay on the pulleys if the rotation is reversed. (By the proper use of an idler or "mule" pulley, reversing quarter-turn belt drives can be satisfactorily operated.) By the same rule, open and crossed belt drive shafts should be parallel, with the pulleys in alignment. Narrow belts are often kept on pulleys by means of flanges on the pulley face. Pulleys for wider belts are **crowned** or slightly greater in diameter at the center than at the edges (see Fig. 3-7). As the belt seeks the highest point on the pulley, the effect of crown is to keep the belt in a central position.

Pulleys are made of cast iron with a rim of rectangular section, and with from four to twelve spokes. Two-piece pulleys which are bolted together at the rim and the hub are more expensive than one-piece or solid pulleys, but are easier to install. Steel pulleys built up of pressed steel rims, hubs, and arms, and welded or riveted, are lighter than cast iron pulleys of the same diameter and face width, and can be run at higher speeds with safety. Pulleys of wood, compressed paper, and compressed fiber are lighter than metal pulleys and have a higher coefficient of friction, and therefore a greater capacity to transmit power for a given belt pull, than metal pulleys.

Fig. 3-19 illustrates a **tight and loose pulley countershaft.** The countershaft *S* is driven from the lineshaft which is coupled to a motor, and rotates continuously. When the belt is on the tight pulley *T*, the countershaft rotates; when the belt is shifted to the loose pulley *L*, the pulley rotates freely on *S*, which remains stationary. The belt shifter is designed so that it will hang vertically for either belt position. The countershaft cone pulley *C* drives the cone pulley on the machine spindle by a vertical belt. For one countershaft speed, three different speeds of the machine spindle are obtainable by shifting the cone belt to a different set of steps.

Fig. 3-20 illustrates a **reversing drive** in which two loose pulleys on countershaft *C* are driven by open and crossed belts from a lineshaft pulley. By varying the size of the loose pulleys, or by using two driving pulleys of different size on the lineshaft, the forward and reverse speeds of this countershaft may be unlike.

Vee-belts are made of cords impregnated with rubber, and are of trapezoidal form. They are made in five standard sections varying from section *A* which is ½" wide and 11/32" high, to section *E* which is 1½" wide and 1" high. The belts are endless and operate either in two grooved

sheaves or in the grooves of a small sheave and on the face of a large pulley as illustrated in Fig. 3-18. Vee-belt and V-flat drives offer a satisfactory solution for industrial transmission problems where the center distance is small and the velocity ratio is high, although these are not necessary conditions.

Round leather belt drives are used for light service as in sewing machine drives and similar applications. Like vee-belts, they may be used for misaligned shafting or for quarter-turn drives. Round belts are available commercially in diameters from 1/8" to 1/2".

Shaft speeds in belt drives are analogous to friction wheel speeds; the speed ratio varies inversely as the pulley diameters.

54. There is some controversy as to the respective merits of **individual and group drives. Individual motor drives** are used on many modern machine tools, are very convenient, and are extremely efficient when the power capacity of a machine is definitely known and when it is generally operated at full capacity. In many machine tools operated at high rates of production, two or more motors are often used on the same machine for more efficient operation of its separate elements.

Group drive by means of a number of countershafts and a lineshaft driven by a large motor is less expensive in initial cost than individual motor drives. Individual motor-driven machines must each have motors that will, on occasion, deliver the full power requirement of that machine even though the machine may usually be operated at half its power capacity. A large group drive motor of a capacity equal to the aggregate capacity of the individual motors is not only less expensive than the small separate units, but it is frequently possible to use a group drive motor with a capacity of three-fourths or one-half that of the individual aggregate. To illustrate: suppose a shop has ten lathes each of which has a maximum power capacity of 5 horsepower; individual drives for these machines will aggregate 50 horsepower even though the machines may operate at half capacity most of the time. For a group drive, however, a 30 horsepower motor would probably furnish sufficient power capacity to drive all the machines, even if several were to operate at full load at one time. The ratio of total anticipated power required to total machine capacity is termed the **diversity factor**; in the foregoing example, the diversity factor is .60 or 60%.

55. Chains are used for hoisting and for power transmission. **Coil chain** is used for hoisting and hauling purposes and may be made of welded wrought iron or steel links. **Twisted link coil chain** is used for general utility purposes but is not used for dangerous lifting. **Stud link chain** is preferred for ship use; the studs tend to prevent stretching and distortion of the links but do not materially affect the chain strength **Wire rope** is also used for hoisting and haulage. It is composed of

cold-drawn steel wires wrapped into strands which are then twisted around a hemp center saturated with lubricant to form the rope. The **diameter** of a wire rope is the diameter of a circle that would just contain the rope. The type of wire rope is specified by two figures: the first figure gives the number of strands in the rope; and the second figure gives the number of individual wires in each strand. For example a $1'' - 6 \times 37$ wire rope has a maximum diameter of 1", and is composed of six strands, each of which has 37 wires. In general, ropes with a large number of wires are more flexible than those with a small number.

Fig. 3-22 shows various types of chain for power transmission purposes. **Detachable link chain** is used for low-speed and light-load power transmission, and for conveyors and elevators of moderate capacity and length. The links can be easily detached and replaced, as illustrated. **Pintle chain** is from two to four times as strong as detachable link chain and can be used with the same sprockets. Both types of chain are usually made up of malleable iron unmachined links. They can be supplied with integral pin, plate, or scraper attachments.

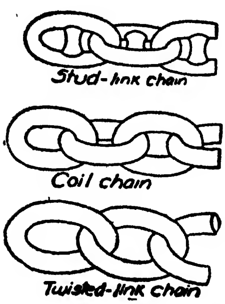


Fig. 3-21. Hoisting Chain.

Steel block, roller, and silent-link chains are used where an exact speed ratio is desired and the center distance of the shafts is too large for gearing. **Block chain** is used for comparatively slow speeds and consists of blocks linked together by connecting links and pins. **Roller chains** consist of alternate links L and M held by connecting pins which are fastened by cotters. The pins also serve to carry the rollers which bear on the sprocket teeth. Roller chains can transmit more power than block chains and can operate at chain velocities up to 1,200 feet per minute. For power requirements too great for single chains, double, triple, or quadruple strand roller chains may be employed.

Silent chain is composed of alternate flat steel links *A* and *B* connected by pins. The links have straight faces in contact with the sprocket, and rotate slightly on the pins as the chain bends around the sprocket. Silent chain is used for heavy loads at speeds up to 1600 feet or more per minute. The silent chain is not actually quiet in operation but is much less noisy than other types of chain in use at the time of its adoption.

The **speed ratio** of a power chain depends upon the numbers of teeth in the driving and driven sprocket wheels; velocity ratios up to 7:1 are satisfactorily employed. Short center drives with high ratios are usually more economical if fine pitch chain is employed, while narrow large-pitch chain is cheaper for low-ratio long-center drives.

56. Toothed gearing is often used in preference to belting, friction drives, or chain drives, where moderate or large amounts of power must be transmitted at a constant velocity ratio. The most important form of toothed gear is that which transmits power between shafts whose axes are

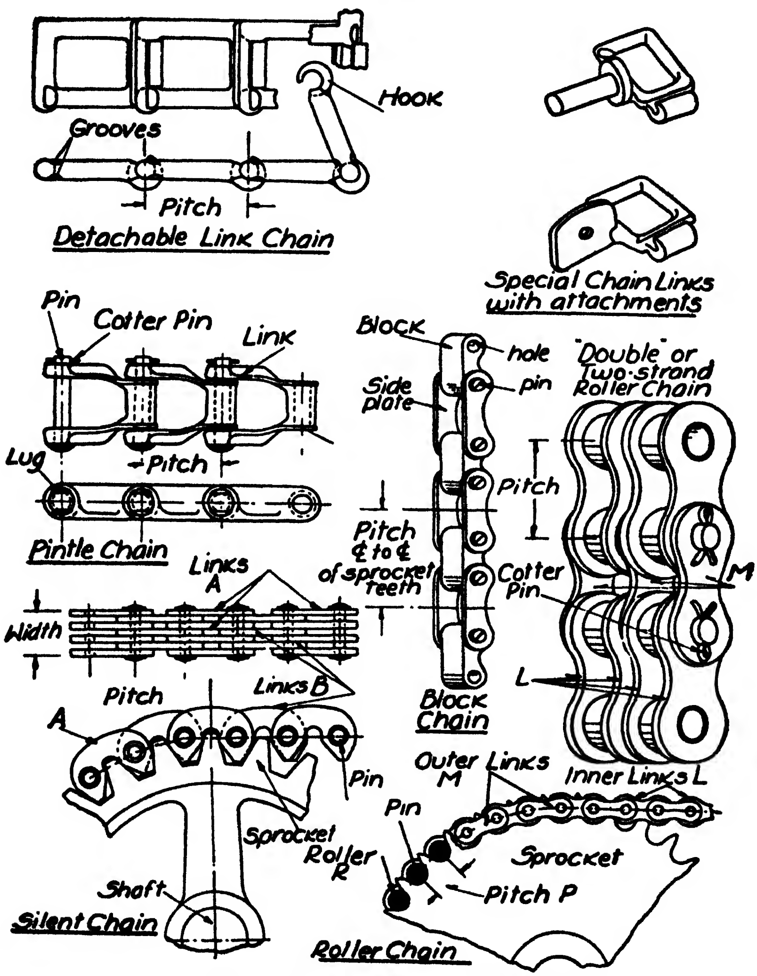


FIG. 3-22. Chains for Power Transmission.

parallel. Fig. 3-23 illustrates the most common form—a spur gear set consisting of the pinion and the gear. The names of some essential parts and elements of the set are given in this illustration.

The **velocity ratio** of a gear set is the ratio of the number of revolutions of one gear to the number of revolutions of the other. If, in Fig. 3-23,

the pinion rotates at 300 r.p.m. and the gear at 150 r.p.m., the velocity ratio is 2:1.

The **pitch circles** of a pair of spur gears are those imaginary circles that are equivalent to the peripheries of a pair of friction wheels that would operate without slipping at the same center distance and velocity ratio as the gears themselves. If the center distance $A - B$ is 6″, and the velocity ratio is as above, the pitch circles of the pinion and gear will have pitch diameters of 4″ and 8″ respectively.

If two spur gears are to operate satisfactorily, the teeth must be of such shape as to transmit smooth and continuous motion, and they must be of the same size. The tooth shape in modern commercial gearing is

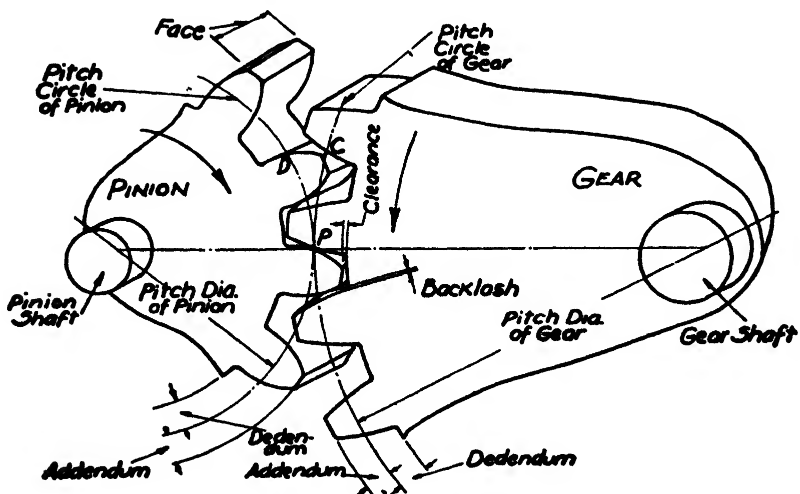


FIG. 3-23. Spur Gearing Nomenclature.

generally that of the involute of a circle, sometimes slightly modified to avoid interference in gears with small numbers of teeth. The size of the gear teeth is measured in two ways. **Circular pitch** is the distance from a point on the profile of one tooth to a corresponding point on the profile of an adjacent tooth measured on the pitch circle. In Fig. 3-23, the arc DP or CP is the circular pitch of the pinion or the gear. The relation of circular pitch and pitch diameter is as follows:

$$\text{Pitch Diameter} = \frac{\text{Number of teeth} \times \text{Circular Pitch}}{\pi}$$

Diametral pitch is the ratio of the number of teeth to the pitch diameter and is expressed as follows:

$$\text{Pitch Diameter} = \frac{\text{Number of teeth}}{\text{Diametral Pitch}}$$

Circular pitches may be given as ½", ¾", 1¼", etc.; diametral pitches as 4, 6, 8, 16, etc. Diametral pitch is commonly employed for commercial gearing since pitch diameters and center distances can be thereby expressed in whole numbers or commonly-used fractions.

It may be seen from the above that the velocity ratio of a gear set is dependent upon, and inversely proportional to, the numbers of teeth in the pinion and gear, or:

$$\frac{\text{r.p.m. pinion}}{\text{r.p.m. gear}} = \frac{\text{Number of teeth in gear}}{\text{Number of teeth in pinion}}$$

The shafts of the set shown in Fig. 3-23 turn in opposite directions. Fig. 3-25 shows an **internal gear set** in which the shafts turn in the same direction. The annular is essentially a spur gear turned inside-out. Fig. 3-24 shows a **pinion and rack** for converting rotary to rectilinear motion. The rack is essentially a spur gear whose pitch diameter approaches infinity as a limit.

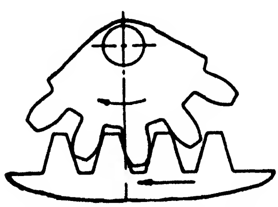


FIG. 3-24. Pinion and Rack.

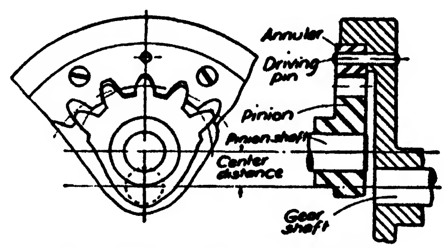


FIG. 3-25. Internal Gearing.

57. In general, power transmission by means of spur gearing is limited to moderate loads and velocity ratios, with pitch-line speeds of 1000 feet per minute or less. When these limits must be exceeded, some form of "twisted-tooth" gear should be employed. Two types of commercial importance are the **helical gear** illustrated in Fig. 3-27 and the double-helical or **herringbone gears** shown in Fig. 3-26. Both types are essentially spur gears with the teeth cut across the face in the form of a helix about the axis of rotation. The helical form of tooth provides gradual engagement and continuous contact of the engaging teeth and thus permits pitch line velocities up to 5000 feet per minute.

58. Bevel gearing is employed to transmit power between shafts whose axes intersect if prolonged. The names of some essential parts of a bevel gear are given in Fig. 3-28. There are two important forms: straight-tooth bevel gearing and spiral-tooth bevel gearing. In straight-tooth bevel gearing, illustrated in Fig. 3-28, the straight line elements of the tooth surfaces intersect at the apex of the set. In spiral-tooth gearing, illustrated in Fig. 3-29, the tooth elements are circular arcs. The tooth

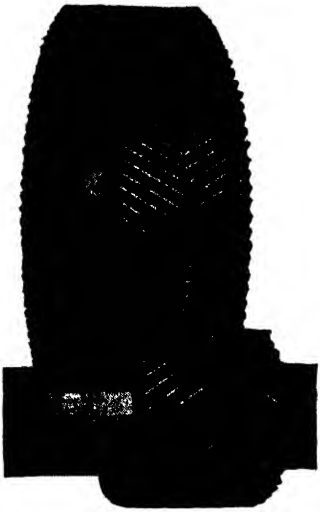


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FIG. 3-26. Herringbone Gearing.

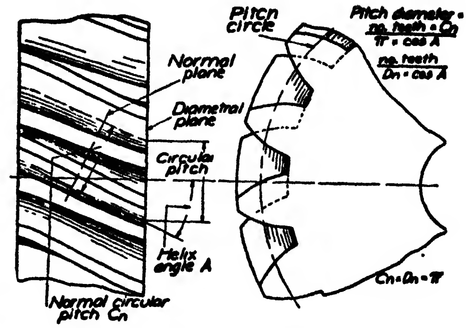

FIG. 3-27. Helical Gear.

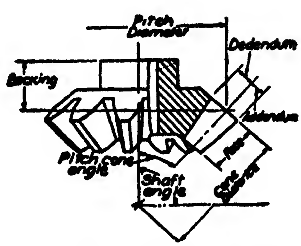

FIG. 3-28. Bevel Gearing Nomenclature.

FIG. 3-29. Spiral Bevel Gearing.

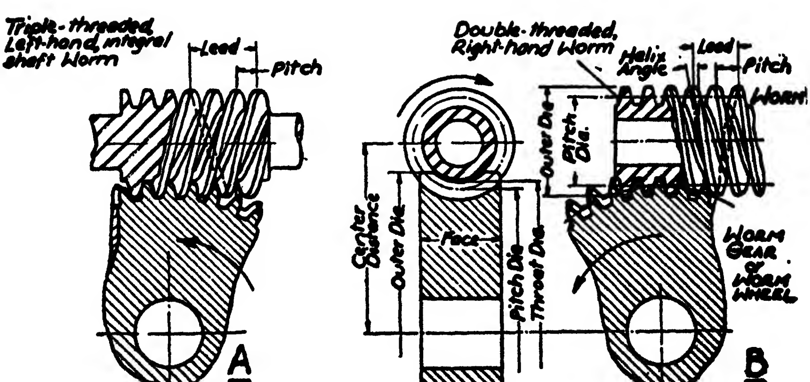

FIG. 3-30. Worm Gearing.

profiles in both types are of involute form. The pitch diameters and velocity ratios of bevel gears are computed in the same manner as in spur gearing. **Spiral bevel gearing** is analogous to helical gearing and is adapted to higher pitch-line velocities than straight-tooth bevel gearing. The angle between the shaft axes of bevel gearing is not necessarily confined to 90°; angular bevel gears are employed to transmit power between shaft axis angles of less than 90°, and other forms may be used when the angle is greater than 90°.

59. Another classification of toothed gearing is that employed to transmit power between shafts whose axes are at right angles, but are neither parallel nor intersecting. **Hypoid gearing,** illustrated in Fig. 3-32, is used almost universally in commercial and passenger automobiles and finds extensive application in industrial drives. **Worm gearing,** illustrated in

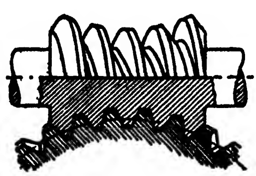

Fig. 3-31. Globoidal Worm Gearing.

Fig. 3-32. Hypoid Gearing.

Fig. 3-30 and Fig. 3-31, is an important industrial drive medium. The more important elements of a worm gear set are illustrated in Fig. 3-30. The pitch diameter of a worm wheel or gear is computed in the same manner as the pitch diameter of spur gearing; circular pitches are generally employed to facilitate the manufacture of the worm. The pitch diameter of the worm may be chosen arbitrarily but is generally selected to correspond to that of a stock *hob,* which is a rotating cutter employed to machine the gear teeth.

The **velocity ratio** of worm gearing may be found from the following:

$$\frac{\text{r.p.m. worm}}{\text{r.p.m. worm wheel}} = \frac{\text{Number of teeth in worm wheel}}{\text{Number of threads in worm}}$$

The number of threads in the worm is equal to the lead of the worm divided by the pitch. If the worm wheel has 60 teeth, the velocity ratio of the set of Fig. 3-30B is 30:1 and that of Fig. 3-30A, 20:1.

Hypoid and worm gearing tooth engagement is largely of a sliding nature, and power transmission by these types is therefore smooth and comparatively noiseless. Worm gearing is therefore employed to transmit large amounts of power at high velocity ratios. The **globoidal type of worm gearing** can transmit heavier loads than the conventional type but is more expensive to construct and install since it requires alignment in three planes.

Fig. 3-33 illustrates a pair of helical gears employed to transmit small amounts of power between non-intersecting shaft axes. This type is commonly, although erroneously, called **spiral gearing.** The load-carrying capacity and efficiency of spiral gearing is comparatively low.

There are numerous other forms of toothed gearing, among which are elliptical gears for variable velocity ratios; intermittent gearing for permitting cessation of motion of the driven member during the cycle of uniform rotation of the driver; and planetary gearing in which one or more pinions rotate about the axis of a fixed gear as well as about their own axes, and thereby provide high reduction ratios.

60. Spur, helical, and bevel gears may be made of cast iron or steel. Pinions for comparatively noiseless drives are often made of bakelite or layers of rawhide, riveted or pinned together. Worms are generally made of heat-treated or hardened steel, while worm wheels may be made of cast iron or bronze, or, in the larger sizes, in a construction employing a cast iron *spider* and a bronze *rim*. Slow-speed drives may permit the use of cast teeth in gearing but modern high-speed drives generally necessitate teeth that are machined, with subsequent grinding and lapping operations if the gear is heat-treated or hardened.

61. A **cam** is a rotating or sliding member which imparts a desired motion or series of motions to another member. There are two important forms of cams; **radial cams** where the follower moves in a plane perpendicular to the axis of the shaft, and **cylindrical cams** where the follower moves in a plane parallel to the axis of the shaft. Each of these types may be further classified as **positive-motion cams** in which the reciprocating motion of the follower is definitely controlled by the cam, and **non-positive motion cams** in which the follower is returned to its starting point by spring or gravity action.

Fig. 3-34 shows a **radial cam** with a flat follower or cam tappet. The cam is integral with the cam shaft. The cam profile is composed of two circular arcs connected by tangent lines. Cylindrical, helicoidal, and plane surfaces are used for cam faces whenever possible, since they are more easily and accurately manufactured than irregular curves.

Fig. 3-35 shows two stages in the operation of a **constant-diameter cam** which is positive in action and does not depend upon a spring for

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FIG. 3-33. Spiral Gearing.

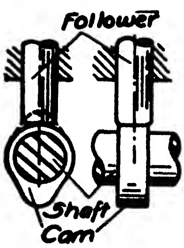

FIG. 3-34. Valve Tappet Cam.

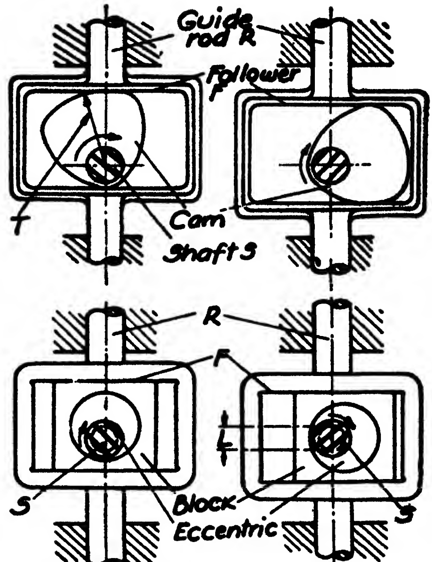

FIG. 3-35. Constant-diameter Cam and Eccentric-and-Block Operation.

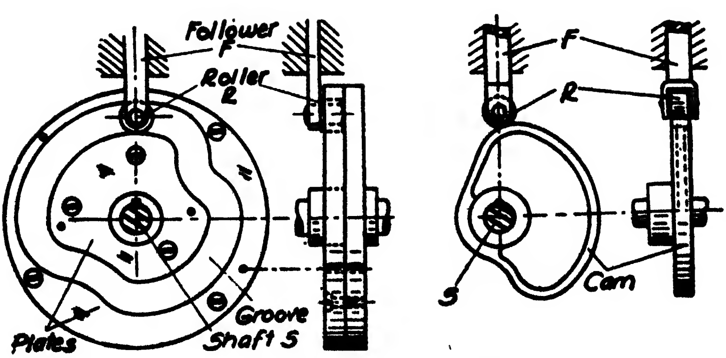

FIG. 3-36. Face and Disc Cams with Roller Followers.

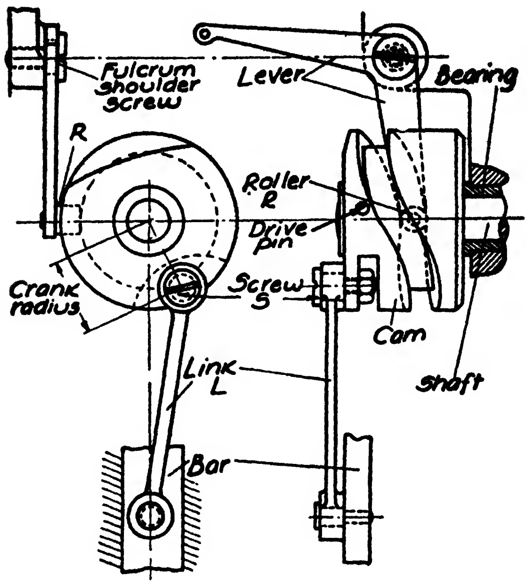

FIG. 3-37. Cylindrical Cam with a Bell-Crank Lever Follower

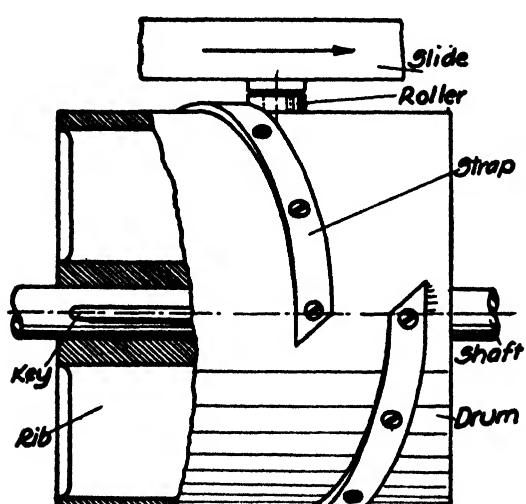

FIG. 3-38. Cylindrical or Drum Cam with Straps.

the return of the follower, as is the case with the cam of Fig. 3-34. Both faces of the follower make line contact with the cam at all times. The constant-diameter cam is somewhat limited in the character of the motion it may transmit and is difficult to manufacture and maintain. The eccentric and block are used in place of constant-diameter cams wherever possible.

The **radial disc cam**, at the right of Fig. 3-36, is similar to the cam of Fig. 3-34. Roller followers are preferred to flat followers because the line contact between the roller and the cam is of a rolling nature, since the sliding is transferred to the pin that carries the roller. The **face cam**, at the left of Fig. 3-36, is a positive-motion cam, but is much more difficult to manufacture than a disc cam because the cam groove must

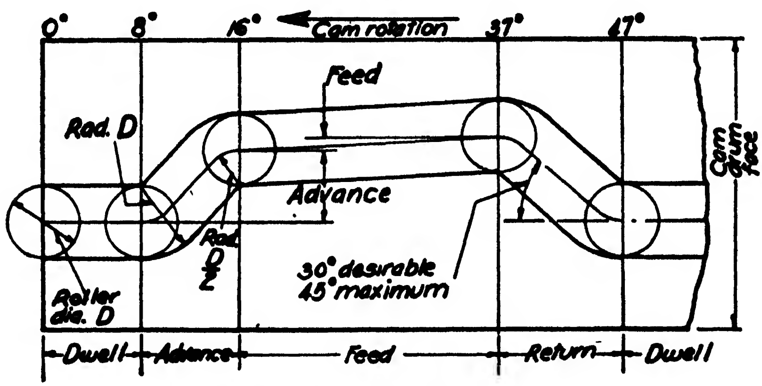

Fig. 3-39. Cylindrical Cam Development.

be of accurate uniform width. This face cam has a cast iron disc on which the inner and outer hardened steel plates are screwed and dowelled.

Fig. 3-37 shows a **solid cylindrical cam** with a bell-crank or lever follower for the thread-controlling function on moderate-speed sewing machines. Fig. 3-38 shows a **drum cam with attached cam straps.** A development or layout of a portion of a cylindrical cam is shown in Fig. 3-39. This development shows uniform or straight-line motion of the roller, modified by an arc equal to the roller radius at the beginning and end of each phase of motion, to permit gradual acceleration and to provide roller clearance. The drum cam may have positive motion and will therefore require a cam strap on either side of the roller, or it may be constructed as shown in Fig. 3-38 where the inertia of the slide is great enough to enable the roller to remain at rest unless acted on by the cam strap.

Cams are used whenever a desired motion is of such character that it cannot be obtained by using cranks or linkages. In Fig. 3-37, the rotating

screw S serves as a *crank pin* and causes the upper end of link L to move in a circular path; the lower end of L moves in a rectilinear path with simple harmonic motion. (The motion of the projection of a point, moving at constant speed on the circumference of a circle, on a diameter of that circle, is harmonic motion.) The length of stroke of the bar is equal to twice the crank radius. Fig. 3-35 shows an **eccentric and block** which transmits harmonic rectilinear motion to the follower F. This mechanism and various types of linkages are preferred to cams because they permit surface or area contact between the moving parts, in contrast to the line contact generally obtained with cams and followers.

CHAPTER 4

UNIT-PRODUCTION SYSTEM MEASUREMENT

62. Practically all engineering and manufacturing processes may be considered under two broad classifications—large-quantity and small-quantity production of parts, devices and machines. These classifications may be referred to as the **mass-production system** and the **unit-production system.** Under the mass-production system, articles are produced in large quantities, generally by comparatively unskilled operators. Methods of manufacture are carefully planned and supervised; special tools and machines are employed wherever feasible; and the operating force is generally trained for specific repetitive tasks. The mass-production system has evolved from the unit production system, under which articles are produced in limited quantities by skilled artisans and mechanics of some versatility by the use of standard tools and machines. In many instances comparatively simple drawings are furnished to the shop or manufacturing division of the organization, which is then responsible for methods of manufacture and such details as allowances for fits, surface finish, etc. In other instances complete specifications for the desired parts are supplied together with instructions for manufacturing procedure, but the parts must still be produced by employing the standard tools and machinery available in the shop.

63. **Measurement** is a fundamental process in all production systems. Measurement generally involves comparison either with some accepted standard or with a mating part. The unit-production system generally employs standard measuring tools and devices; the mass-production system may employ highly specialized measuring tools in which the initial expense and the cost of maintenance are more than offset by decreased operational costs.

The **significance** of any measurement is determined by the degree of accuracy to which elements and parts may be measured. There are two kinds of accuracy that are important in engineering measurements, **accuracy of form and accuracy of size.** By accuracy of form is meant not only the exact duplication of irregular profiles, but also the accuracy of form embodied in straight-edges, squares, true cylinders and cones, involutes, etc. Accuracy of size implies comparison with some accepted standard. The most important problem of accuracy of size is the determination of linear measurements. **The fundamental British unit of**

length is the yard, which is the distance at a temperature of 62° F., between two fine lines on gold plugs in a bronze bar at Westminster. The **fundamental metric unit of length** is the meter, which is the distance at a temperature of 0° C., between two fine lines on a platinum-iridium bar at the International Bureau of Weights and Measures at Sevres, France. The meter is the fundamental unit of length on which the **United States inch** is based. In 1866, the United States Congress established the relation between the yard and the meter as:

$$\frac{1 \text{ yard}}{1 \text{ meter}} = \frac{3600}{3937}$$

from which the following equivalents are obtained:

$$1 \text{ meter} = 39.37 \text{ inches}$$
$$1 \text{ inch} = 25.4000508 \text{ millimeters}$$

The simple ratio of

$$1 \text{ inch} = 25.4 \text{ millimeters}$$

has been approved by the American Standards Association for United States industrial practice. A difference of two-millionths of an inch per inch of length prevails between this simple ratio and that established by Congress. The error is of little significance in ordinary industrial practice and can be ignored for convenience.

Angular measurements are made in degrees, minutes, and seconds. Angular measurements can be originated by subdividing a circle, and are not based upon a fixed physical standard, although industrial measurements of this character are usually based upon commercial standards.

64. The most important example of **accuracy of form** is exemplified in the manufacture and use of straight-edges, surface plates, and squares. There are two methods of producing any of these important elements, reproduction and origination. To **reproduce** a straight-edge, it is necessary to have a master edge for comparison. After the part has been machined as accurately as possible on a machine tool, its edge is coated with red lead or Prussian blue. The master straight-edge is then rubbed along the edge, which will cause the high spots to become visible. These spots are removed with a hand scraper as illustrated in Fig. 4-1. The edge of the part is again coated with paint, subjected to the rubbing action of the master edge, and again scraped. The process is one of successive approximations, which may be compared to a rapidly converging series whose final truth is directly dependent upon the time and effort involved.

To **originate** a straight-edge, three parts are simultaneously prepared. These three edges are shown in Fig. 4-2 (with obviously exaggerated rough edges). Edges 1 and 2 are first scraped until they fit as

shown in operation *A*. (The edge of each must be either a straight line or the arc of a circle.) Edge 3 is then scraped to fit edge 1 as in operation *B*. Edges 2 and 3 are then compared as illustrated in operation *C*. If these do not coincide, the successive scraping operations are continued. This process was invented by Sir Joseph Whitworth in 1840 and marks the beginning of the attainment of precision. The definition of a straight-

Photo by E. S. Miller, Jr.

FIG. 4-1. Scraping a Straight-edge.

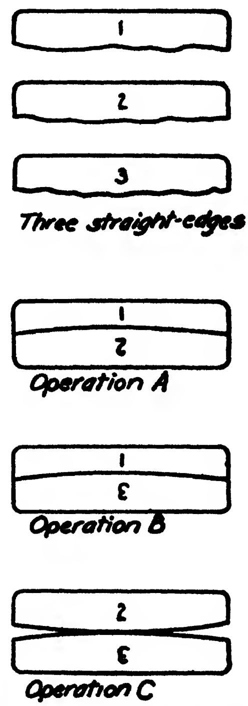

FIG. 4-2. Originating a Straight-edge.

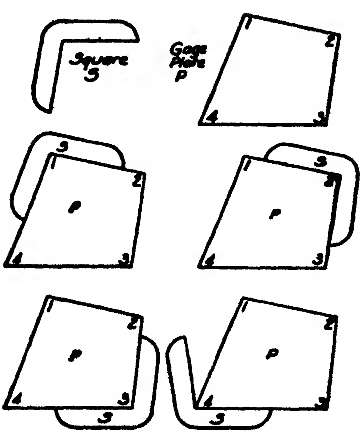

FIG. 4-3. Originating an Internal Square.

edge is directly dependent upon the process, and is as follows: "A perfect straight edge is one of three, any two of which, when placed together, coincide throughout their length.

Surface plates may be reproduced or originated in the same manner as straight edges. Fig. 4-3 shows a method of originating an internal square. The square is made as accurately as possible by mechanical means

and is then fitted to one corner of a gage plate. Corners 2 and 3 of the plate are then scraped to fit the square. When the square is applied to corner 4 of the plate, the error will be shown (multiplied by four). The square is corrected as nearly as possible, again applied to corners 1, 2, and 3 of the plate, which are fitted to it, and tested at corner 4. The process is continued until the error at corner 4 disappears when, obviously, both plate and square are correct. The gage plate may be preserved for making future squares by the reproduction method.

65. In any machine or device there are certain relations between the dimensions of the component parts that are essential if the unit is to function properly. In the burring machine illustrated in Chapter 3, for example, the spindle should rotate freely but without any perceptible shake in the bushings. The bushings, on the other hand, should fit tightly in the frame. The difference in size between the bore of the bushing and the diameter of the shaft is referred to as **clearance**; the difference in size between the outer diameter of the bushing and hole in the frame is referred to as **interference** since the bushing is larger than the hole. Both these **intentional differences** in the sizes of mating parts are termed **allowances.**

The American Standards Association has adopted eight classifications of fits which are described in A.S.A. Bulletin B 4a-1925. A **class 1 loose fit** has a large allowance, provides for considerable freedom where accuracy is not essential, and is used in agricultural and mining machinery. A **class 2 free fit** has a liberal positive allowance, and is used as a running fit for speeds higher than 600 r.p.m. A **class 3 fit** has a medium positive allowance, and is used for the more accurate machine tool and automotive parts. A **class 4 snug fit** has a zero allowance, necessitates considerable precision, and is the closest fit that can be assembled by hand. A **class 5 wringing fit** has a zero to negative allowance, and gives practically metal-to-metal contact. A **class 6 tight fit** has slight negative allowance, requires light pressure to assemble, and is used for gears, pulleys, and extremely long contacts. A **class 7 medium force fit** has negative allowance, requires considerable pressure to assemble, and the parts are considered permanently assembled. A **class 8 heavy force and shrink fit** has considerable negative allowance, and is used for press fits in steel or for shrink fits where heavy force fits are impractical.

66. Steel rules such as illustrated in Fig. 4-4 are graduated in thirty-seconds and sixty-fourths of an inch. A capable mechanic can estimate within one-third of a division, or an accuracy of five to six thousandths of an inch. Some rules are provided with a short right-angle hook attached to one end to facilitate taking measurements over rounded corners or from an edge.

Calipers are used for measurements to within .007", and may be of the spring or firm joint variety. Fig. 4-4 illustrates the method of reading an outside caliper; inside caliper distances may be read by placing the legs

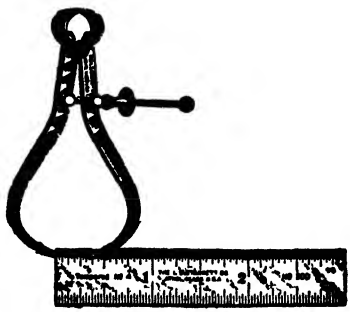

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FIG. 4-4. Outside Spring Caliper.

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FIG. 4-5. Inside Firm-joint Caliper.

of the caliper on a rule and placing one leg and the end of the rule against a flat surface. **Scribing calipers** are used to scribe lines parallel to an edge, and are also used to describe intersecting arcs on bosses or the ends

Photo by E. S. Miller, Jr.

FIG. 4-6. Hermaphrodite or Scribing Caliper.

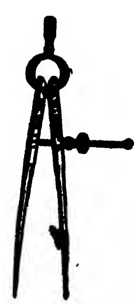

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FIG. 4-7. Spring Dividers.

of bars to help locate centers which may then be punched and center-drilled **Spring dividers** have hardened points and are used for scribing circles and arcs. It is necessary to have a punched center to support and locate one leg of the dividers when scribing circles or arcs.

67. Measurements to .001″ may be determined by using a **vernier caliper** illustrated in Fig. 4-8. The caliper consists of a primary scale along which two heads, *V* and *D*, may be moved. Head *D* is generally clamped in position and the adjusting nut rotated until head *V* is correctly positioned. The vernier is a small scale with a certain number of divisions whose combined length equals that of a different number of divisions, usually one more or one less, on the primary scale of the instrument. There is therefore a small difference in the lengths of the vernier and primary scale divisions and the readings of the instrument depend upon this differ-

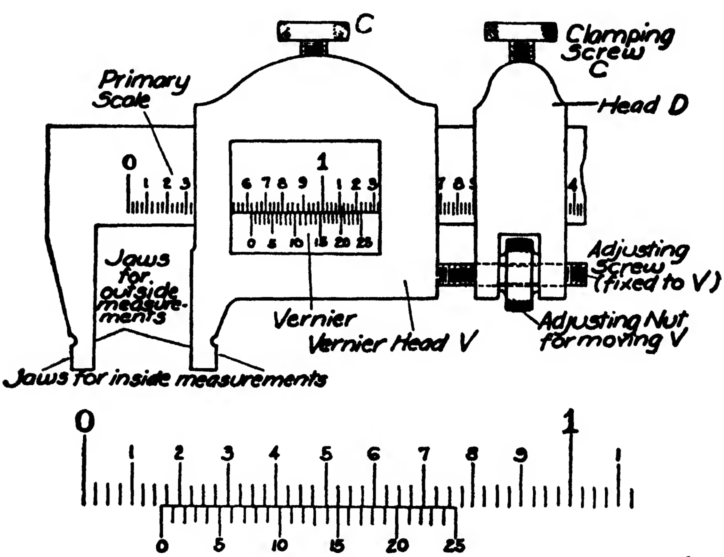

FIG. 4-8. Vernier Caliper.

ence. In the vernier caliper of Fig. 4-8, the primary scale is graduated in fortieths of an inch, or .025″. There are twenty-five vernier scale divisions whose combined length equals that of twenty-four primary scale divisions. The difference between the division lengths is therefore .025″ − .024″ = .001″. When the zero line on the vernier coincides with the primary scale graduations, the caliper size is read directly from the primary scale. In the illustration of the caliper shown, this reading is 0.625″. This leaves a space between the primary scale graduations and the vernier graduations 1, 2, 3, etc., of .001″, .002″, .003″; the difference between the coincidence of these two sets of graduations increases .001″ at every point until the scale and vernier lines again coincide at the twenty-fifth vernier graduation. Therefore, if the third vernier line coincides with a scale line, the vernier zero line is .003″ past the scale line to the left of the vernier zero. The

actual reading of the caliper is therefore equal to the sum of the scale reading to the left of the vernier zero, and the number of thousandths of an inch indicated by the coincidence of a vernier graduation and a scale graduation. In the figure below the caliper the primary scale reading is .150″, and, as the 15 line on the vernier coincides with a primary scale line, the final reading of the caliper is .150″ + .015″ or .165″.

Vernier calipers are made in 6″, 12″, 24″ and 36″ sizes, and can be used for both external and internal measurements. They are generally

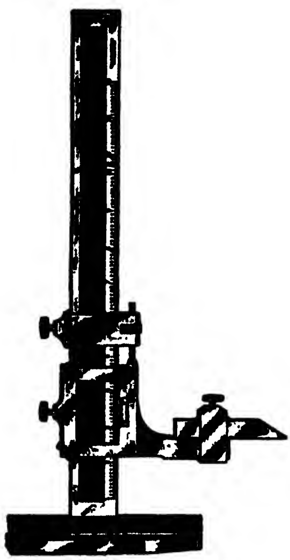

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FIG. 4-9. Vernier Height Gage.

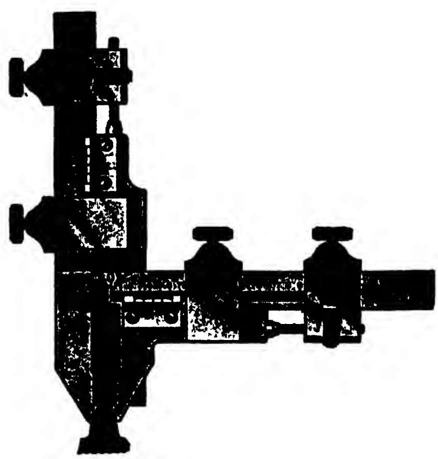

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FIG. 4-10. Gear Tooth Vernier.

graduated to read on one side for outside and on the other side for inside measurements. Fig. 4-9 shows a **vernier height gage** designed to measure and mark off vertical distances from a plane surface. Fig. 4-10 shows an instrument for measuring the chordal thickness of a spur gear tooth while determining the distance from the top of the tooth to the chord. The instrument is essentially a combination of a vernier caliper and a vernier depth gage.

68. The **micrometer caliper** is an instrument for measuring directly to thousandths, and estimating to quarter-thousandths of an inch, within its range. The principle of operation of this instrument is based on an accurate screw with forty threads to the inch turning in a fixed nut to vary the distance between two measuring faces. One of these measuring faces

is at the end of a fixed anvil which is attached to the micrometer frame; the other is at the end of the movable spindle which is integral with the screw and the thimble. As the thimble is integral with the screw, it travels along the barrel (which is a part of the frame). The graduations on the barrel conform to the pitch of the screw; one space therefore represents

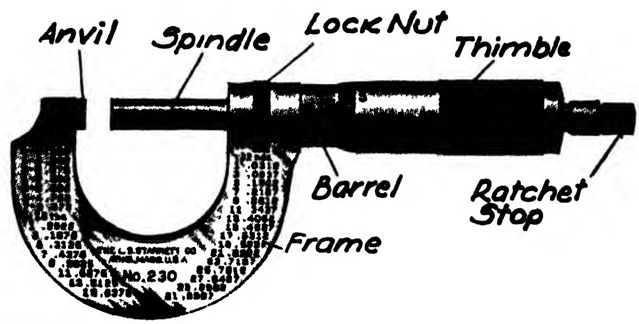

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FIG. 4-11. 1" Micrometer Caliper.

.025", or the distance that the spindle and thimble move axially when the screw turns once. Each division on the bevelled edge of the thimble represents one twenty-fifth of a screw turn and is therefore equal to .001". As an illustration, the barrel reading in Fig. 4-11 indicates eight complete turns of the thimble or 8 × 0.25 = .200". In addition, the thimble has been turned

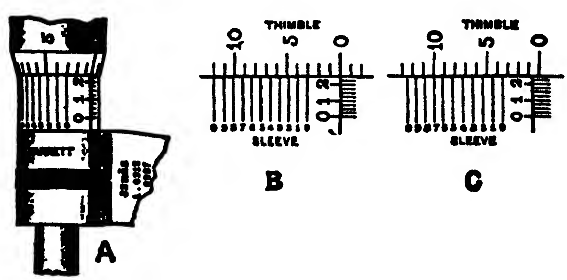

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FIG. 4-12. Vernier Micrometer Caliper.

very slightly more than two spaces or .002" +. The total distance between the anvil and spindle faces is therefore .202" +.

Vernier micrometer calipers enable the user to read the instrument to one ten-thousandth of an inch. The principle of operation is similar to that of the vernier caliper; the thimble graduations serve as the primary scale and a scale on the barrel is used for the vernier reading. The

micrometer reading is taken by adding the barrel divisions, the thimble divisions with respect to the axial line on the barrel, and the vernier reading. To illustrate, in *B,* Fig. 4-12, the barrel scale shows ten spaces, the thimble zero is on the barrel index line, and the vernier zeros coincide with the thimble graduations. The reading of the instrument is consequently .2500". In case *C,* however, the vernier reading of 7 must be added to the barrel and thimble reading, giving a measurement of .2507".

Micrometer calipers generally have a 1" range; that is, instruments for measuring from 0" to 1", from 1" to 2", and from 4" to 5", by thousandths or ten-thousandths, are commercially available. Micrometers may be obtained with or without a ratchet stop, which is an auxiliary thimble to provide a uniform pressure for every measurement. The lock nut or clamp ring is used to lock the spindle at any point so that the micrometer may be employed as a gage with a fixed opening.

Fig. 4-13 shows an **inside micrometer caliper** designed for internal and linear measurements. The micrometer screw has a movement of ½", and the necessary range can be obtained by inserting various extension rods in the head. The instrument is furnished with a handle which is perpendicular to the barrel so that holes of considerable depth may be conveniently measured. A small steel base is commercially available in which the instrument may be mounted so that it may be used as a height gage.

In the **screw thread micrometer caliper** of Fig. 4-14, the movable spindle is pointed and the end of the anvil is of the same form as the thread to be measured. In measuring screw threads, the angle of the spindle point and the sides of the anvil vee contact the surface of the thread so that the reading of the caliper indicates the pitch diameter of the thread. The zero on the thimble represents a line drawn through the plane *AB.*

Micrometer heads, consisting of a barrel, spindle, and thimble, without an anvil or frame, are commercially available for attachment to tools and machines where precision measurements are required.

69. Precision gage blocks are small, hardened steel blocks of a definite thickness or length, with the size of each block stamped or marked on it. The dimension of a block represents the distance between two flat, parallel, perfectly finished surfaces on opposite sides. A 1" block, for example, does not vary more than a few millionths of an inch from this size.

Precision gage blocks may be used singly or in combination to give an almost unlimited variety of sizes within their range. Two or more blocks are assembled by "wringing" the blocks together. The contact surfaces of the assembled blocks are so nearly perfect planes that they will resist separation in a direction perpendicular to the contact faces with a force considerably greater than the atmospheric pressure on the area of the con-

tact. This adhesion results from the presence of a very thin liquid film of oil or condensed water vapor. The adhesive qualities are sufficiently great to permit one pair of contact surfaces to support the weight of a number of blocks as illustrated in Fig. 4-15.

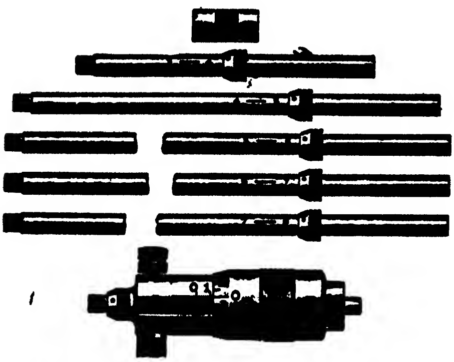

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Fig. 4-13. Inside Micrometer Caliper (2″ to 8″ Range).

Precision gage blocks are sold singly or in sets. One set, for example, may be employed to obtain any dimension from .100″ to 10.000″ by increments of .0001″. When the required dimension is more than .500″, two or more stacks of blocks can be built up to identical dimensions from the same set for checking against each other or for use on several jobs simultaneously. Gage block attachments are commercially available to facilitate the use of the blocks in layout and measuring operations. Inside and outside caliper jaws enable the blocks to be used as fixed gages, and a scriber attachment will permit their use for layout work.

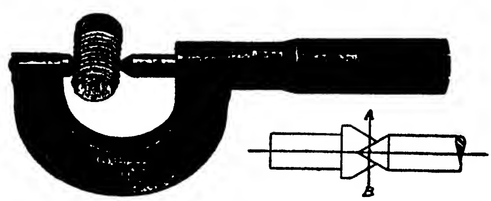

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Fig. 4-14. Screw Thread Micrometer Caliper.

Ford Motor Co.

Fig. 4-15. Adhesive Qualities of Johansson Gage Blocks.

Precision gage blocks, whether singly or in combination, are extensively employed for checking micrometer and vernier calipers and production gages, as illustrated in Fig. 4-16.

70. Optical measuring methods are extensively employed for precision work. The **toolmakers' microscope,** Fig. 4-18, is used by machinists and toolmakers for measuring and checking tools, gages and other work requiring a high degree of precision. It consists of a microscope mounted

adjustably on a vertical column and located over a stage on the base of the instrument. The microscope gives a greatly-enlarged image of the point measured, and shows objects and their movement in their natural aspect, not reversed as in the ordinary laboratory microscope. The eyepiece has in its focal plane a special disc with cross lines that intersect at the center of the field at angles of 30°, 60°, 90°, 120° and 150°. The stage of the instrument consists of two slides at right angles to each other, each of which has a 1″ range controlled by micrometer screws, and which is graduated to read directly to .0001″. A special protractor eyepiece is also available, by means of which angles within a range of 30° may be measured.

In using the instrument the work is placed on the stage and clamped in position by means of the clamps shown in Fig. 4-18, or by special clamps or work-holding devices. Suppose it is desired to determine the distance between the edge of a block and the center of a cylindrical hole in the block. The stage is adjusted until the crossline in the eyepiece is in line with the edge and the screw reading is taken. The cross slide is then adjusted until the crossline coincides with the edge of the hole and the screw reading is again taken. The difference of the readings added to the radius of the hole gives the required distance.

Measuring machines, of either mechanical or optical character, are commercially available for very accurate internal and external measurements. The use of the principle of light wave interference in **optical flats** affords another accurate measuring process that is used for checking gages and gage blocks. While these devices are employed in modern industry, particularly in gage manufacture, they really belong to the scientific rather than to the productive classification of measuring equipment.

71. Fig. 4-19 shows a **telescoping gage** which is used for internal measurements. The small leg of the head telescopes within the large leg, and may be locked at any distance by the knurled screw at the end of the handle. These gages are made in sets with a range of ½″ to 6″, and the legs have spherical ends ground to the radius of the smallest hole the gage will enter. The gage is inserted in a hole; the legs are locked; and the gage is then withdrawn and measured with a micrometer caliper.

Fig. 4-20 shows a **surface gage** which consists of a base, an adjustable arm, and an adjustable scriber which may be fastened at any point. The surface gage is extensively employed for layout and test work. The scriber may be replaced by the dial and arm *A* and *B* of Fig. 4-21 to serve as a height gage.

The **dial test indicator,** Fig. 4-21, is a gage which has a graduated dial *A*, and an indicating hand which is connected to a test point *M* by a system of levers, so that a slight movement of the test point is greatly

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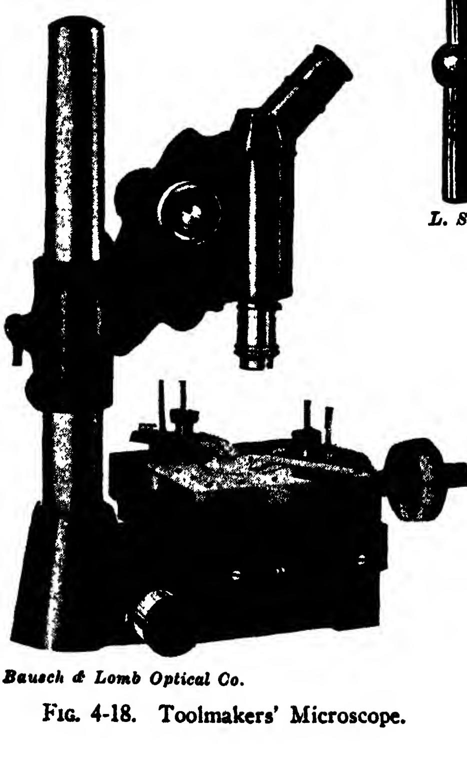
FIG. 4-16. Using Johansson Gage Blocks to Check a Solid Snap Gage.

Ford Motor Co.

FIG. 4-17. Using Johansson Gage Blocks on a Fixture to Check Location of Holes.



Bausch & Lomb Optical Co.

FIG. 4-18. Toolmakers' Microscope.

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FIG. 4-19. Telescoping Gage.

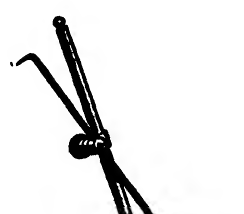

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FIG. 4-20. Surface Gage.

magnified by the indicating hand. The test point is placed in contact with the part to be tested and variations in size or alignment are shown by the movement of the hand on the dial. Several types of test-points, *C, D,* and *E,* and a shank for holding the indicator in a lathe tool post are illustrated.

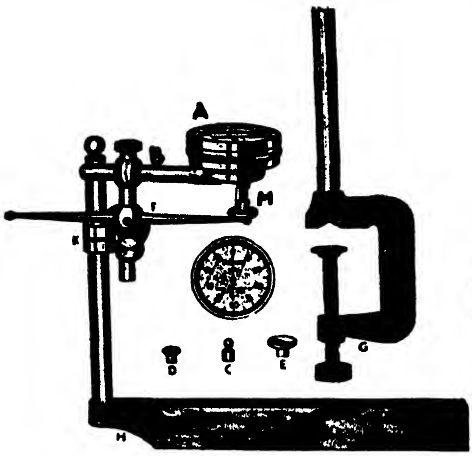

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FIG. 4-21. Dial Test Indicator.

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FIG. 4-22. Precision Square.

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FIG. 4-23. Combination Set.

Photo by E. S. Miller, Jr.

FIG. 4-24. Using the Combination Square As a Marking Gage.

Photo by E. S. Miller, Jr.

FIG. 4-25. Finding the Center of a Cylindrical Bar by Using a Center Head and Scriber.

The clamp *G* is employed to support the dial when the tool is to be clamped to a circular shaft or arbor.

Fig. 4-23 shows a combination set which consists of a 12" steel rule with a center head, a bevel protractor head, and a combination square head. The bevel protractor is graduated to degrees, may be locked in

position, and is used for measuring bevels, angles and tapers. The combination square head may be employed as an adjustable blade square, as a miter gage, as a depth gage, or as a marking gage as illustrated in Fig.

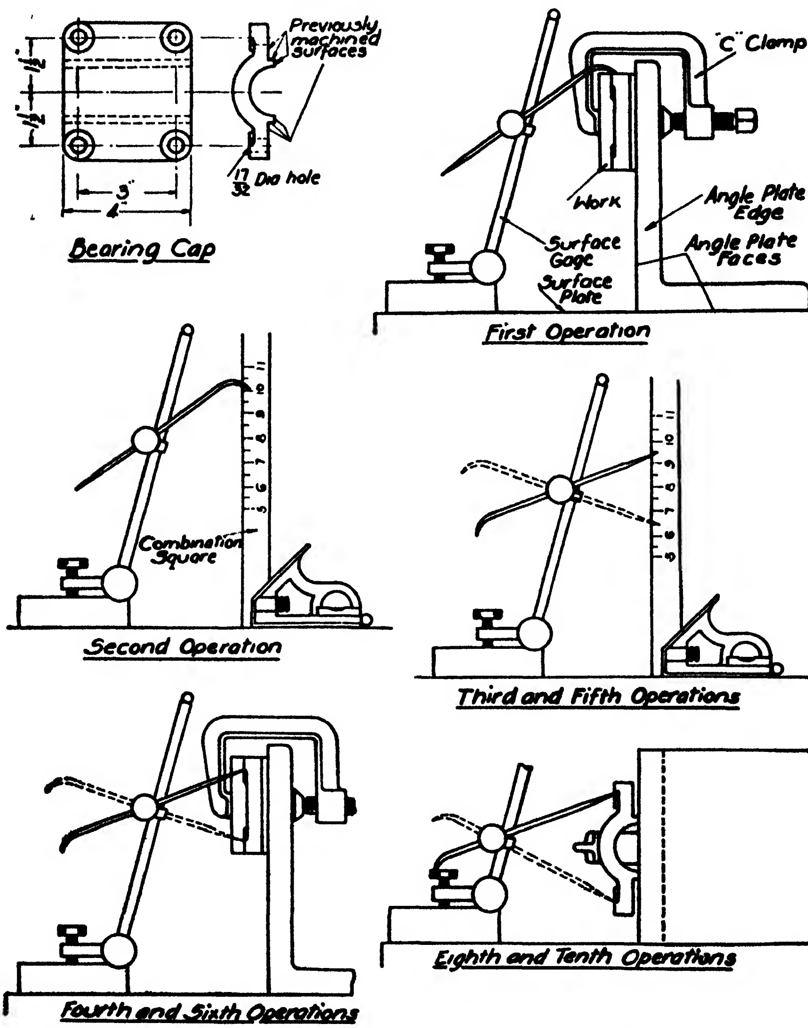

FIG. 4-26. Locating the Centers of Four Holes by Employing a Surface Gage, Combination Square and Angle Plate.

4-24. The square is equipped with a removable scriber which is held in a friction bushing. The perpendicular leg of the square also carries a level glass so that the head may be used as a level or as a plumb in conjunction with the blade.

Taft-Pierce Mfg. Co.

FIG. 4-27. Checking a Part Mounted on an Adjustable Angle Plate by a Vernier Height Gage Mounted on an Angle Iron and a Box Parallel.

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FIG. 4-28. Adjustable Parallels.

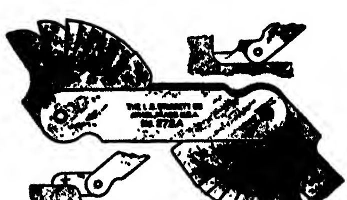

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FIG. 4-29. Fillet or Radius Gage.

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FIG. 4-30. Screw Pitch Gage.

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FIG. 4-31. Drill Gage.

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FIG. 4-32. Gage for Sheet Metal Thickness.

Parallels are steel bars of rectangular section that are generally in pairs for measuring and supporting work. They are finished within one-half thousandth of their nominal size and the edges are parallel or square within this limit. There are three forms: the solid parallel, the box parallel shown in Fig. 4-27, and the adjustable parallel of Fig. 4-28.

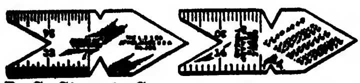

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FIG. 4-33. Center Gage.

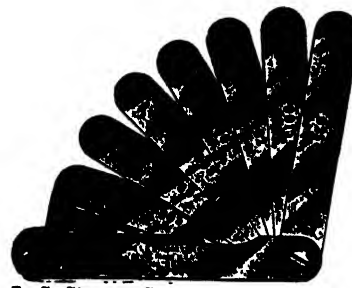

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FIG. 4-34. Thickness or "Feeler" Gage.

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FIG. 4-35. Center Punch.

72. Fig. 4-26 illustrates the sequence of operations in locating the centers of the four holes in a bearing cap so that they may be drilled. The work is clamped by a C-clamp, to an angle plate which has mutually-perpendicular finished faces and edges, and adjusted so that the face of the bearing cap is horizontal. The accuracy of this adjustment is determined

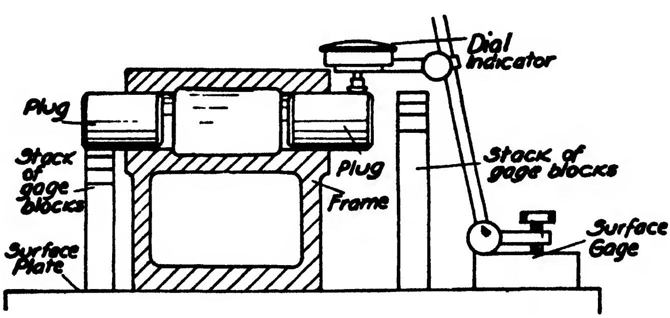


FIG. 4-36. Two methods of Testing the Center Height and Parallelism of the Bearing Hole in a Frame.

with a surface gage. The height of the face of the work is then determined as illustrated in operation 2. As the centerline of one set of holes is ½" below this face, the surface gage scriber point is set ½" below the face height, as illustrated in operation 3, and a line is drawn across the bearing cap bosses as shown in operation 4. The scriber is next set 3" below this

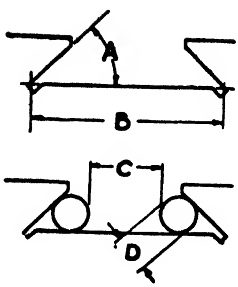


Fig. 4-37. Measuring Dovetail Slides.

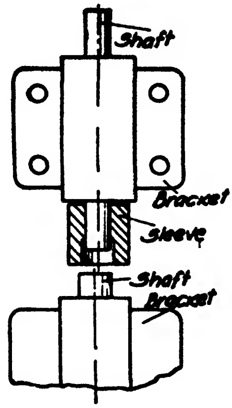


Fig. 4-38. Checking Alignment of Two Brackets.

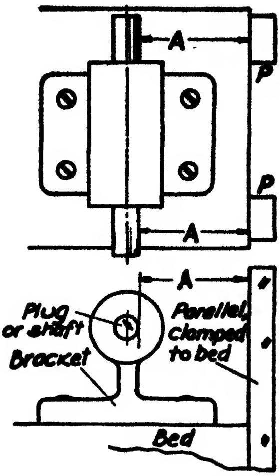


Fig. 4-39. Checking Alignment of Shaft Hole in Bracket with Finished Edge of Machine Bed.

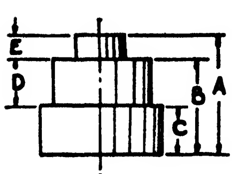


Fig. 4-40. Measuring Cylinder Lengths.

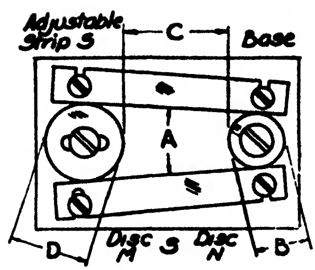


Fig. 4-41. Method of Originating Tapers.

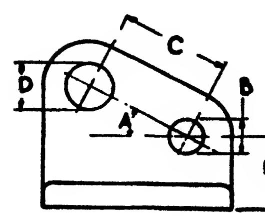


Fig. 4-42. Special Bracket

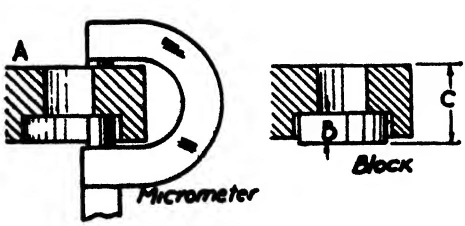


Fig. 4-43. Two Methods of Measuring the Length of a Hub.

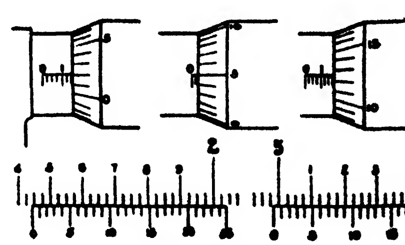


Fig. 4-44. Micrometer and Vernier Caliper Settings.

line, as seen in operation 5, and a line is drawn across the second set of bosses, operation 6. The angle plate is then turned on its side, thus bringing the lines already drawn to a vertical position, and the operational sequence is repeated for another pair of lines.

73. Fig. 4-36 shows two methods of testing the height of the central hole in the frame of the burring machine illustrated in Chapter 3. In each instance tightly fitting plugs are inserted in the bushing holes. At the left the center distance is obtained by gaging with a suitable stack of precision gage blocks, and by adding the radius of the plug to the stack height to obtain the center distance. If the same stack of blocks can be used at both ends, the axis of the hole must be parallel to the base of the frame. At the right the center distance is measured by passing a dial indicator, mounted on a surface gage, over the plug, and then obtaining the same dial reading on another stack of gage blocks whose height is equal to the center distance plus the plug radius. The center distance could of course be measured by using the plugs and a vernier height gage.

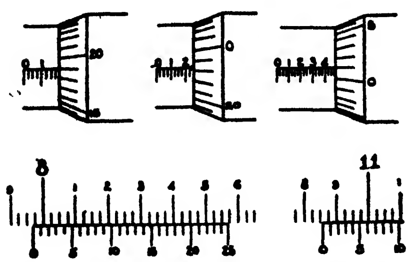


FIG. 4-45. Micrometer and Vernier Caliper Settings.

Fig. 4-38 shows a method of checking the alignment of two brackets by using a sleeve which is bored to fit both shafts. Fig. 4-39 illustrates how one of the brackets of Fig. 4-38 is aligned with the edge of the machine bed on which it is fastened. Parallels are clamped to the finished edge of the bed and measurements are taken from their faces to the shaft or plug in the bracket.

CHAPTER 5

SAND-CASTING PROCESSES

74. **Casting** is a process that utilizes the characteristic of **fusibility.** The most widely used method, sand-casting, consists of pouring molten metal into suitable molds or recesses in sand, and allowing it to cool; upon removal of the sand, the metal will have a shape and form approximately that of the mold.

The simplest form of sand-casting is illustrated in Fig. 5-1. In **open bed molding,** the foundryman digs out a space in the foundry floor of the proper size and shape, compacts the surfaces of the mold, and then pours the molten metal into it. There are several undesirable features of this process. First, it is extremely difficult to produce a mold of the required size and shape, except for very simple parts. Second, the molten metal, if poured from any height, will destroy a portion of the mold, and cause the sand to be washed away and reappear somewhere in the casting. Third, the upper surface of the casting, being exposed to the air, will cool much more quickly than the lower surface and a warped or twisted casting may result. Fourth, the upper surface of the casting will probably be badly oxidized and have a thick scale or coating of iron oxide on it. Fifth, the casting may have a comparatively low density.

The first of these undesirable features may be eliminated by employing a suitable pattern or form with which the mold may be made; the second can be remedied by using a pouring basin and a gate, so that the molten metal may flow into the mold; the other disadvantages of this process can be countered by using a considerable volume of sand above the mold, and allowing the molten metal to rise in channels so that a hydrostatic head of some height will act on the casting as it is being poured.

Fig. 5-2 shows a **two-part mold** ready for pouring. The box containing the sand is termed the **flask** which in this particular mold is composed of two parts, the upper portion or **cope,** and the lower portion or **drag.** The molten metal is poured into a pouring basin, flows along a runner down a vertical gate **sprue,** and along a gate into the **mold space.** As the mold space is filled the excess material rises in another vertical channel termed a riser sprue. The gate and riser sprues furnish hydrostatic pressure to insure proper density of the casting, and also serve as sources of supply or shrinkage heads for molten metal as the interior of the casting shrinks in cooling. Any loose sand in the mold tends to travel to the top of the riser sprue, and since this portion of the

casting is cut off after the casting is removed from the mold, it will not affect the soundness of the casting.

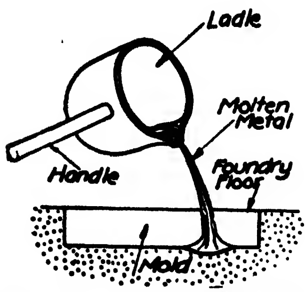


Fig. 5-1. Open Bed Molding.

75. Fig. 5-3 shows a cast iron machined part for which a casting is to be made. Fig. 5-4 shows the wooden **pattern** for this part. The pattern must be larger than the machined part so as to compensate for machining, casting shrinkage, and draft.

Machining allowance is the amount of excess material required to permit proper machining or finishing of the surfaces of the casting. Machining allowance varies with the size and shape of the casting and is generally determined by the pattern maker. A cylinder 2" in diameter and 4" long, for instance, might be cast $2\frac{1}{4}$" in diameter and $4\frac{1}{4}$" long so

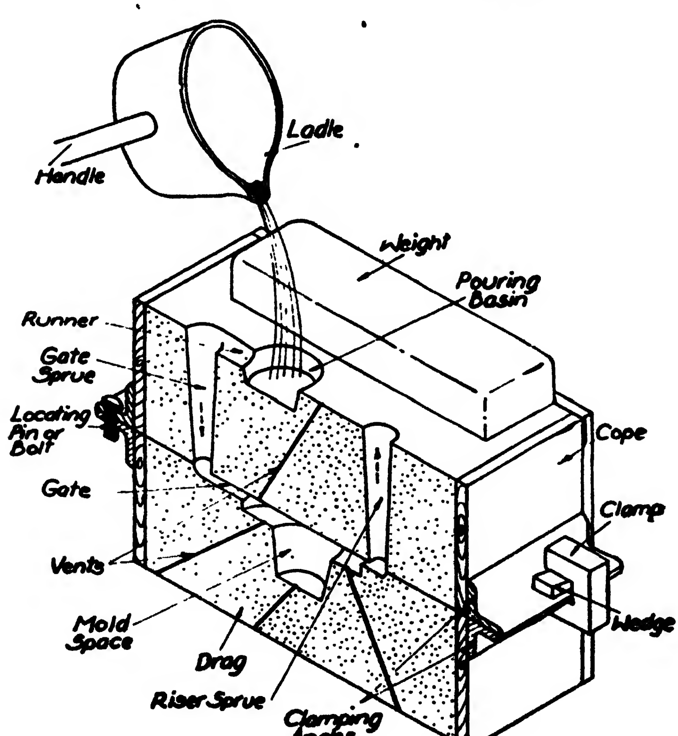


Fig. 5-2. Completed Mold with Two-part Flask.

as to permit $\frac{1}{8}$" to be removed in machining its surfaces. Should the cylinder be 12" long, however, a cast diameter of $2\frac{1}{2}$" might be required

on account of the possibility of warpage of the casting. For the part illustrated in Fig. 5-3, 1/4" allowance on all diameters and 1/8" allowance on lengths will probably suffice. The diameters will therefore become 10 1/4" and 4 1/4", and the lengths 1 1/8" and 3".

Most metals contract during cooling and provision must therefore be made for this change in dimension. The **shrinkage allowance** depends upon the size of the casting and the material of which it is made, and is generally specified as a definite amount per foot of length or diameter. The usual allowance for cast iron is 1/8" per foot; for steel 1/4" per foot; for aluminum 3/32" per foot; for brass 3/16" per foot. In order that the

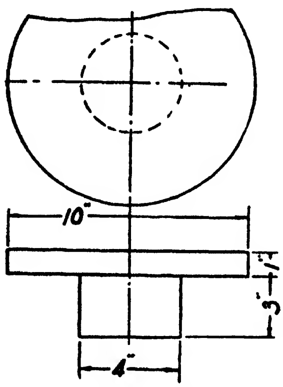


FIG. 5-3. Finished or Machined Part, for Which a Casting Is to be Made.

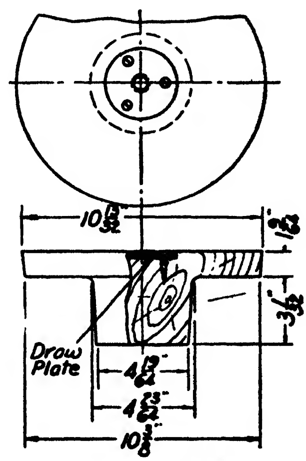


FIG. 5-4. Pattern.

casting may have the required dimensions, the 10 1/4" diameter must be increased to approximately 10 3/8", the 4 1/4" diameter to 4 19/64", the 3" length to 3 1/32" and the 1 1/8" length to 1 9/64". Patternmakers seldom calculate these dimensions; they use a special rule termed a **shrinkage rule** in which a total length of 24 1/4" is divided into 24 apparent inches and octaval fractions thereof.

In order to remove the pattern without injury to the mold it should be tapered in the direction in which it is drawn or removed from the mold. The necessary increase in size of the upper portion of the pattern is known as **draft allowance.** The amount of draft allowance depends upon the size of the casting, and the manner in which the pattern is drawn from the mold. The pattern shown in Fig. 5-4 will be drawn in a direction parallel to the axis of the component cylinders. It will therefore be necessary to change these cylinders into frusta of cones. Draft allowance is generally

¼" per foot of depth. The upper diameters of the two component cones are therefore 1/32" and 1/16" larger than the lower diameters.

The final dimensions are given in Fig. 5-4. The corner at the juncture of the cone frusta is **filleted** so as to eliminate stress concentrations and preclude the possibility of washing away sharp corners of the mold. The fillet may be removed in machining. Inserted in the upper face of the pattern is a metal **draw-plate** which permits the pattern to be easily drawn by a screw or eyebolt inserted in the threaded hole in the center, and serves as a plate which can be tapped with a punch, or rapped, to loosen the pattern in the mold so that it can be drawn.

76. Fig. 5-5 shows the first molding operation. The pattern is placed top downward on a molding or bottom board and the drag is placed over it in an inverted position. A mixture of silica sand, clay, and water, known as green sand, is sifted over the pattern. A riddle or sieve is used for this part of the process to eliminate any large foreign particles. After the pattern is covered with this facing sand, rough or unsifted sand is shoveled into the drag and tightly pounded or **rammed** into place by using the hand rammer shown in Fig. 5-10. (Molders often use hand rammers in pairs, one in each hand.) After the sand is rammed, any excess is removed by passing a straight-edge or strickle across the edges of the drag. The drag is then turned over, replaced on the molding board, and the upper surface sprinkled with **parting sand** which is a sand that will not absorb moisture to any extent. The cope is then placed on the drag as illustrated in Fig. 5-6, and is located by bolts or pins placed in the clamping angles. Green sand is then sifted over the surface of the pattern, and conical wooden plugs to serve as gate and riser sprue molds are placed in position and held in place until green sand has been shoveled into the cope and rammed. The mold is then **vented,** which is done by sticking it with a fine stiff wire at numerous places. The vents permit the escape of gases generated by the contact of the molten metal and the sand. The sprue plugs are drawn from the cope, the bolts or pins removed, and the cope is lifted from the drag. (The parting sand permits easy separation of the two parts of the flask because the cope and drag sand cannot stick together.) The pattern is **rapped** by using a punch and hammer and is then **drawn,** as illustrated in Fig. 5-7, by screwing an eyebolt into the hole in the draw-plate and pulling it up.

After the pattern is drawn the molder cuts the gate and the passage to the riser sprue in the drag, and the pouring basin and runner in the cope, and repairs any broken portions of the mold by using the trowel or the slick illustrated in Fig. 5-10. (Molders are generally supplied with a variety of these tools for different kinds of molds.) Loose particles of sand are removed by a jet of air either from a hand bellows or from

a compressed air pipe. The surfaces of the mold are brushed or dusted with powdered plumbago so as to give a smooth surface to the casting. The

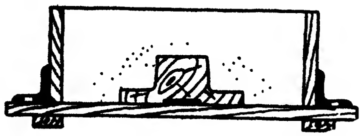


Fig. 5-5. Filling the Drag.

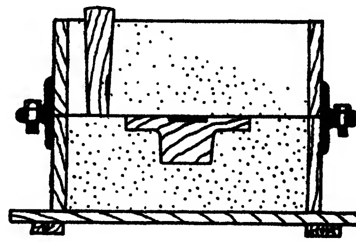
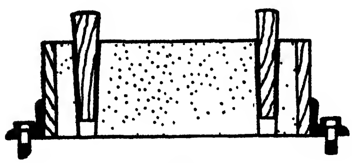


Fig. 5-6. Filling the Cope.



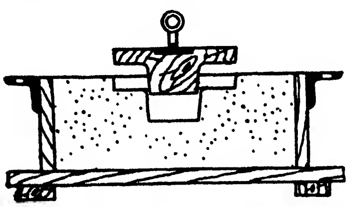


Fig. 5-7. Removing the Cope and Drawing the Pattern.

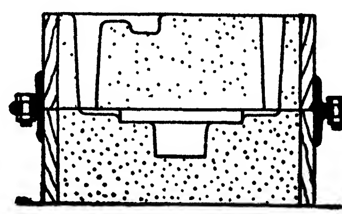


Fig. 5-8. The Completed Mold.

cope is replaced on the drag, as illustrated in Fig. 5-8, and the two are located with respect to each other by the bolts or pins. The two parts of the flask are then clamped together either by nuts on the bolts, or by clamps

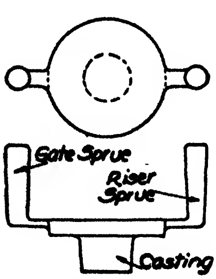


Fig. 5 9. The Completed Casting As It Is Shaken Out from the mold.

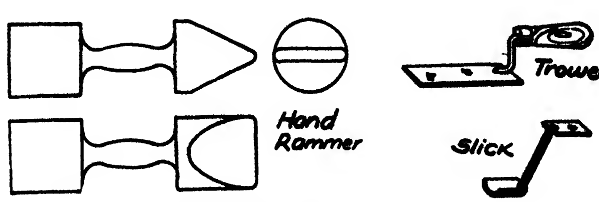


Fig. 5-10. Molder's Tools.

and wedges, as shown in Fig. 5-2. Weights are placed on top of the flask to counteract the tendency of the molten metal to lift the sand, and the mold is ready for the pouring operation.

77. The molten metal is carried from the source of supply in a ladle. Ladles are made with one handle for one-man operation; with two handles for two-man operation; or with trunnions and a gear-operated hand wheel, as illustrated in Fig. 5-14, so that they may be transported by an overhead crane. (Ladles with a hole and valve in the bottom, instead of the usual spout, are sometimes employed for casting steel.) In pouring large castings, several pouring basins are sometimes cut so that two or more ladles may be simultaneously employed to fill the mold. The mold must be completely filled at one pouring. After pouring, the mold is allowed to stand until the iron is cold since premature removal of the casting may result in chilling and air-hardening the surfaces. The cope and drag are then separated, the sand is shaken out, and the casting appears as in Fig. 5-9. The

Alcoa Aluminum and Its Alloys (Aluminum Co. of America)

FIG. 5-11. Slicking a Sand Mold.

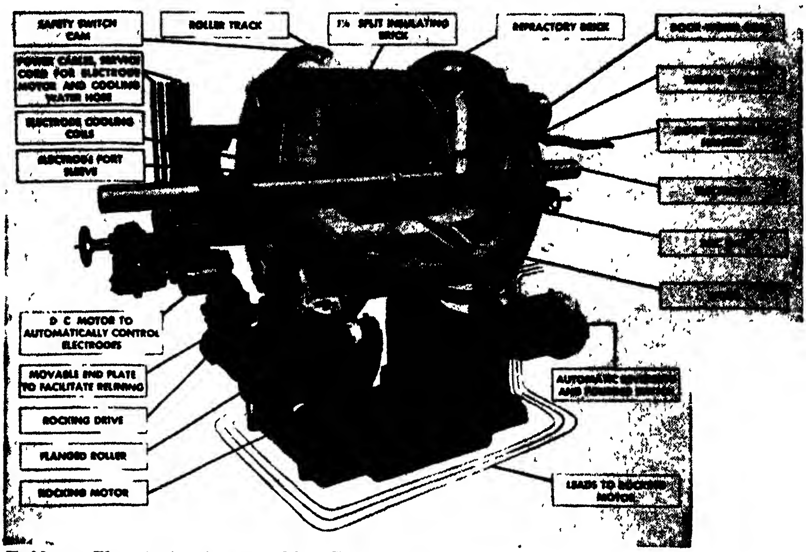
The Tabor Mfg. Co.

FIG. 5-12. Cupola.

sprues are cut off, the casting is cleaned, and is then ready for machining.

78. There are several varieties of sand used in foundry practice. **Green sand** is a mixture of silica sand with 18% to 30% clay, having a total water content of from 6% to 8%. The clay and water furnish the bond for the green sand. **Dry sand** is generally green sand that has been dried or baked after the mold is made. Dry sand molds are more

expensive than green sand molds on account of the baking operation, but the castings have a better surface finish and are less subject to internal



Kuhlman Electric Co. (Detroit Elec Furnace Div.)

FIG. 5-13. Indirect Arc Rocking Furnace.

defects. Dry sand molds are often used for large work so that casting spoilage—much more costly in large than in small work—will be avoided.

Kuhlman Electric Co. (Detroit Elec. Furnace Div.)

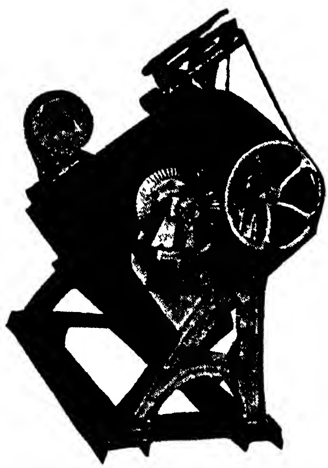
FIG. 5-14. Filling a Ladle from an Electric-arc Furnace.

A core is a section or portion of a mold which is employed to produce voids of a definite size. Cores are made from silica sand mixed with

core oil in the proportion of 75 parts of sand to 1 of oil. Cores are generally made in wooden forms, often in several parts. After they have been shaped in the forms, they are removed, dried in a core oven, and pasted together.

Core oil is generally composed of from 50% to 60% linseed oil, 25% rosin, and light mineral oil. The mineral oil is used as a thinner to facilitate mixing the core sand. Pitch or flour and water may be used in large cores for the sake of economy.

79. Metals may be melted for foundry purposes in a cupola, an electric furnace, or a crucible furnace. A **cupola,** Fig. 5-12, consists essentially of a vertical steel shell of uniform diameter, which is lined with a refractory material such as firebrick. The bottom of the cupola is lined with fire-clay and a layer of sand. The lower portion of the cupola has a second shell built around the first. The wind-box or space between the two shells serves as a receptacle and distributor for the air required in melting the metal. The air is admitted from the wind-box into the body of the cupola by radial openings called tuyeres, which serve as valves and regulate the air flow.



Crucible Furnace Co.

Fig. 5-15. Tilting Furnace.

The cupola is usually employed for melting cast iron which is used in two forms: **pig iron,** which is iron in the form of billets or pigs from the blast furnace; and **scrap iron,** which is composed of broken-up articles, gate and riser sprues from previous casting operations, and defective castings. Often a mixture of pig iron and scrap iron is employed. The cupola is charged by placing a layer of wood with some coke, on the bottom or floor of the cupola, and, after ignition and combustion have started, by filling the interior to a definite level with the bed charge of coke. A charge of iron is then placed on top of the coke; alternate charges of coke and iron continue until the cupola is filled to the proper height, and a final charge of limestone is added as a fluxing agent.

The limestone combines with the impurities in the iron, and with such portions of the cupola lining as burn off, to form a substance called **slag** which floats on top of the molten metal and thereby prevents oxidation and decarburization. When the metal is melted, it is drawn off through a tap hole on to the pouring spout from which it flows into a ladle placed in position underneath. Cupola sizes vary from one to fifteen

tons of melted iron per hour. The usual charging ratio is about one pound of coke to ten pounds of iron.

The **electric furnace** may be employed for melting both ferrous and non-ferrous metals. The melting heat is obtained by the passage of electricity between two electrodes which remain clear of the molten bath at

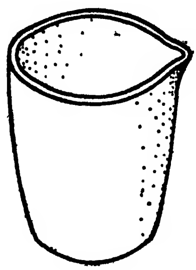
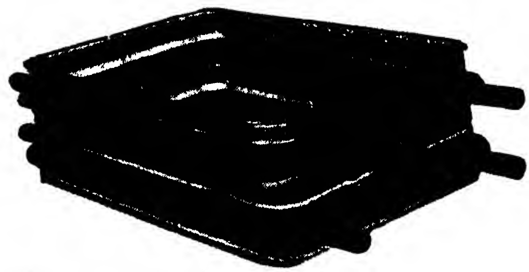


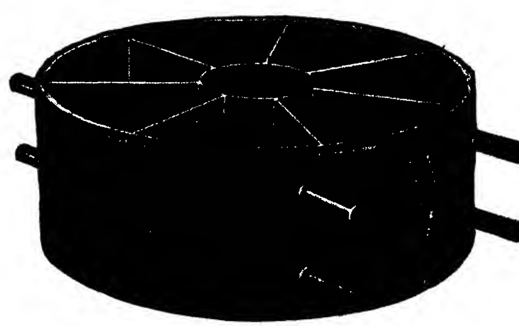
FIG. 5-16. Crucible.



Black-Sivalls & Bryson Inc.

FIG. 5-17. Two-part Steel Flask.

all times. The shell rocks or oscillates during the melting cycle and the metal charge is thereby heated both by direct radiation from the arc and by conduction from the refractory lining. The electric furnace permits a close control of the chemical analysis of the molten bath and the time and temperature relationship for a given melting operation. When the melting cycle is complete, the shell is tilted forward to a pouring position and all or a portion of the charge is poured into a ladle, as illustrated in Fig. 5-14.



Black-Sivalls & Bryson Inc.

FIG. 5-18. Two-part Circular Flask with Cross Bars for Supporting Sand.

A **crucible furnace**, such as illustrated in Fig. 5-15, consists of a steel shell lined with refractory material in which a **crucible**, Fig. 5-16, surrounded by coke, is placed. Combustion of the coke by the admission of air melts the metal charge in the crucible. The air is taken from the atmosphere by the blowers, one of which is shown in Fig. 5-15, preheated by passing it through the wind-box surrounding the shell, and flows upward through the grate on which the crucible is placed. The furnace has a cover which can be lifted and swung to one side by using the handle arrange-

ment shown. The furnace can be tilted for pouring by the hand wheel and gearing.

Crucibles are made of fire-clay and other refractory materials, and may be obtained in a variety of shapes and sizes. Two commonly used materials for high-temperature crucibles are carborundum (Carbofrax) and alumina (Alfrax). Crucible heating furnaces may also be heated by gas or oil.

Gas- or oil-fired open-flame furnaces are in wide use. These furnaces are generally horizontal barrel-shaped steel shells lined with a refractory material, and are supported by trunnions at the ends. Oil or gas and air are admitted through the trunnions and the flame plays directly on the metal charge. The pouring is done through an opening perpendicular to the axis of the shell.

80. Fig. 5-19 represents a hollow cylinder for which a casting is required. Fig. 5-20 shows **a two-piece wooden pattern** with wooden dowels in the upper half and corresponding holes in the lower half. The pattern is larger than the casting to compensate for shrinkage and to allow for draft on the cylindrical ends. Fig. 5-22 shows three views of the **core-box** for molding one-half of the core. It also shows the completed core; two halves are made separately, dried in a core oven, and pasted together. Fig. 5-22 shows the first molding operation; the lower half of the pattern is placed face downward on a bottom board, the drag placed over it, and the drag filled with sand and rammed. The drag is then reverted, and the upper half of the pattern is placed on the lower half correctly located by the dowels. The cope is placed on the drag, located by bolts or pins, parting sand is sprinkled on the surface of the drag, gate and riser sprue plugs are placed in position, and the cope is filled with sand and rammed. After venting, the cope and drag are separated and the pattern half in each part of the flask is drawn. The core is placed in position in the drag, and the cope is replaced as in Fig. 5-25. The core is supported by extensions or **core prints** which fit in core print spaces in the mold. Fig. 5-25 shows the appearance of the casting with the sprues still attached after some of the sand has been shaken out.

81. Long interior cores, or those which are supported at one end only, may tend to sag and cause uneven wall thicknesses in castings. Sometimes wires are used to strengthen fragile cores but this may cause some difficulty in removing the sand from the casting. Fig. 5-26 illustrates several forms of chaplets which are used to support long cores. (The chaplet height is equal to the space between the core and the mold). When the casting is poured, the chaplet fuses with the metal. The use of chaplets should be avoided if the surface is subsequently machined or if the casting is subjected to pneumatic or hydraulic pressure, since defective castings

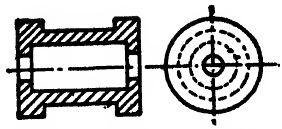


Fig. 5-19. Hollow Cylinder.

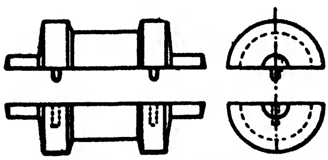


Fig. 5-20. Two-piece Pattern for Hollow Cylinder.

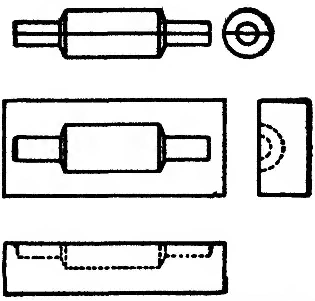


Fig. 5-21. Core Box and Core for Hollow Cylinder.

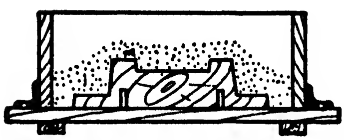


Fig. 5-22. Filling the Draw (Hollow Cylinder Casting).

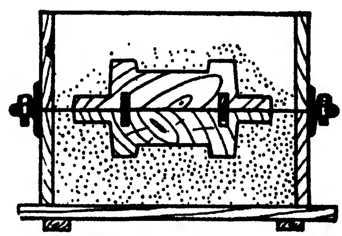


Fig. 5-23. Filling the Cope (Hollow Cylinder Casting)

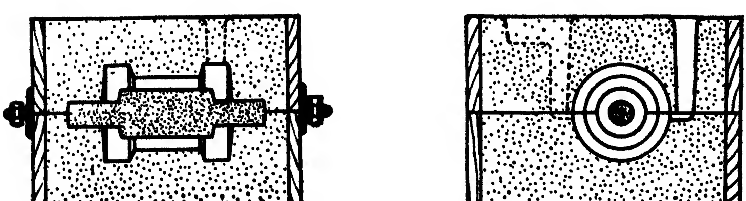


Fig. 5-24. Completed Mold for Hollow Cylinder Casting.

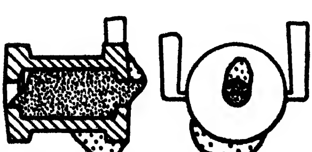


Fig. 5-25. Completed Hollow Cylinder As Shaken Out from Mold.

Fig. 5-26. Chaplets.

may result because of improper fusion, or because of air or gas pocketing at the chaplet.

82. Fig. 5-27 shows the frame or base for the burring or countersinking machine illustrated in Fig. 3-2. There are two methods of molding this part. Fig. 5-28 shows a two piece pattern with slots or dovetailed grooves in each half for the **loose pieces** of Fig. 5-29. The loose pieces are placed in the slots, and the drag placed and filled, as shown in Fig. 5-31. The drag is then reverted, the other pattern half placed in position, and the cope half of the flask filled. The cope and drag are taken apart and the pattern drawn from each as illustrated in Fig. 5-32, leaving the loose piece of Fig. 5-29 in the mold. Fig. 5-33 illustrates the subsequent removal of the loose piece. Fig. 5-34 shows the completed mold with the hole core of Fig. 5-30 in place and the riser and gate sprues cut.

Fig. 5-35 shows another pattern for the same casting. This pattern has a **core print** on the base of the casting for the core illustrated in Fig. 5-36. After the molds are made and the pattern is drawn, the core for the boss is placed in position as shown in Fig. 5-38.

Fig. 5-39 shows a sheave or grooved pulley which may be molded by three different methods. The first may be termed the **false core** method and is illustrated in Figs. 5-40 to 5-48. Fig. 5-40 shows the two-piece dowelled pattern; Fig. 5-41 shows the lower half of the pattern on the bottom board with the drag in place.

Fig. 5-42 shows the reverted drag with the sand cut away from the space for the false core. Parting sand is sprinkled along the cut surface as well as over the face of the drag. Fig. 5-43 shows the upper half of the pattern in position. The false core is filled in and its surface covered with parting sand. Fig. 5-44 shows the cope in position partially filled with sand. Fig. 5-45 shows the cope lifted from the drag, and the upper half of the pattern being removed. The cope is then replaced on the drag as shown in Fig. 5-46. Fig. 5-47 shows the flask inverted, the drag lifted off, and the lower half of the pattern removed. The drag is then replaced on the cope and the whole flask reverted. The completed mold appears in Fig. 5-48 (the gate and riser sprues, vents, clamps, etc. are not shown). This method of handling the green sand false core insures that it is adequately supported at all times.

Figs. 5-49 to 5-52 show another method of molding a sheave. This method employs a **three-part flask.** The first molding operation in this method is similar to that of Fig. 5-41. Fig. 5-49 shows the reverted drag with its entire face cut away and sprinkled with parting sand. Fig. 5-50 shows the center section or **cheek** of the flask in place. Fig. 5-51 shows the cope in place, and 5-52 illustrates the method of separating the cope, cheek and drag, and removing the pattern. Both the false-core and

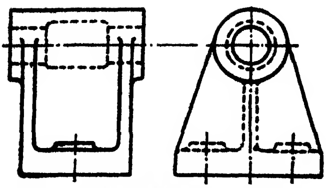


Fig. 5-27. Machine Frame.

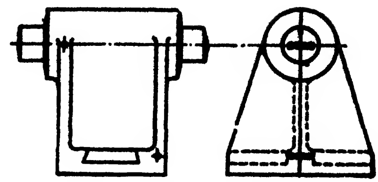


Fig. 5-28. Machine Frame Pattern with Slots for Loose Pieces.

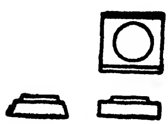


Fig. 5-29. Loose Piece Serving As Pattern for Boss.

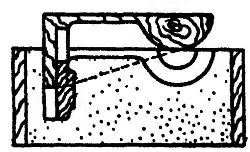


Fig. 5-32. Drawing Pattern, with Loose Piece Left in Mold.

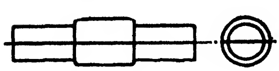


Fig. 5-30. Hole Core for Machine Frame.

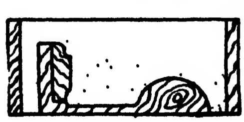


Fig. 5-31. Filling the Drag; Loose Piece in Place.

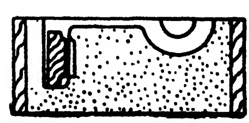


Fig. 5-33. Removing Loose Piece from Mold.

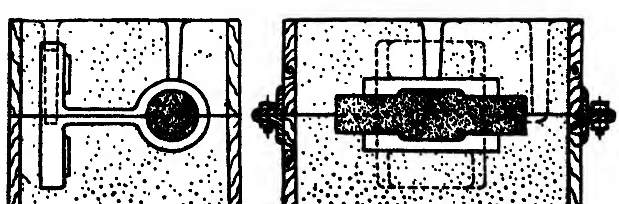


Fig. 5-34. Completed Mold for Machine Frame.

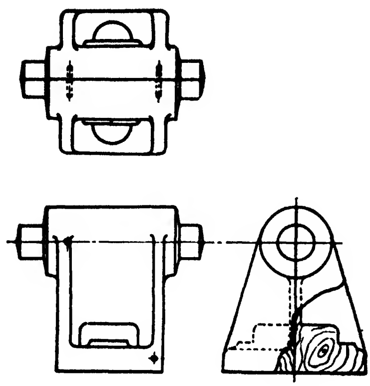


Fig. 5-35. Machine Frame Pattern with Core Prints.

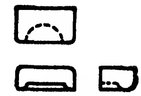


Fig. 5-36. Core for Half of Boss.

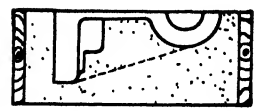


Fig. 5-37. Mold Half After Pattern is Drawn.

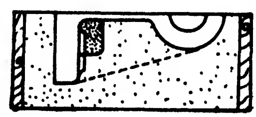


Fig. 5-38. Mold Half with Cores in Place

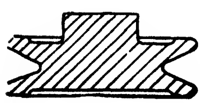


Fig. 5-39. Sheave or Grooved Pulley.

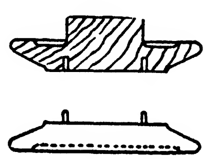


Fig. 5-40. Two-piece Pattern for Sheave.

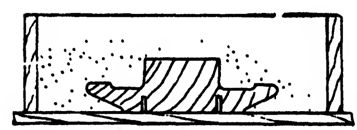


Fig. 5-41. Sheave Molding: Operation 1A

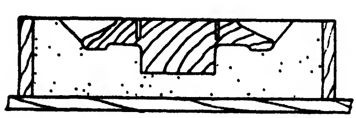


Fig. 5-42. Sheave Molding: Operation 2A.

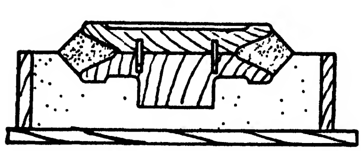


Fig. 5-43. Sheave Molding: Operation 3A.

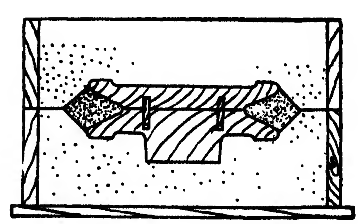


Fig. 5-44. Sheave Molding: Operation 4A.

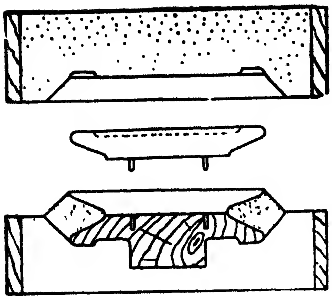


FIG. 5-45. Sheave Molding: Operation 5A.

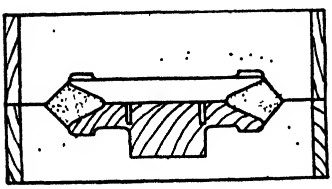


FIG. 5-46. Sheave Molding: Operation 6A.

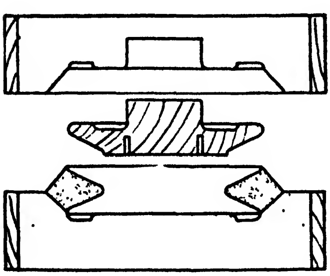


FIG. 5-47. Sheave Molding: Operation 7A.

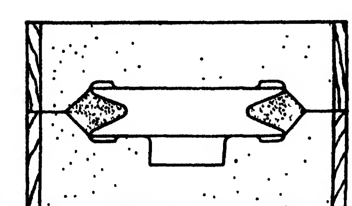


FIG. 5-48. Sheave Molding: Completed Mold.

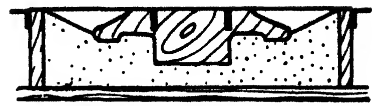


FIG. 5-49. Sheave Molding: Operation 2B.

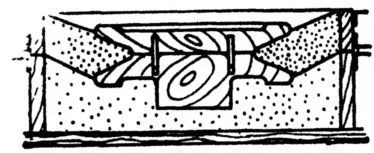


FIG. 5-50. Sheave Molding: Operation 3B.

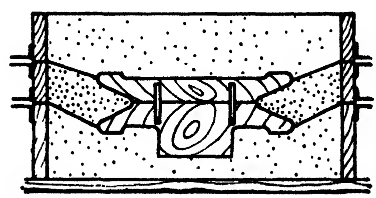


FIG. 5-51. Sheave Molding: Operation 4B.

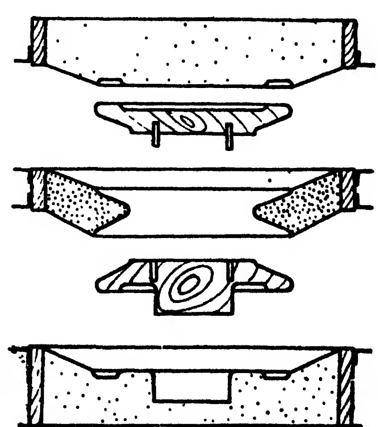


FIG. 5-52. Sheave Molding: Operation 5B.

the three-part flask methods require considerable molding skill and very careful handling.

The third method, illustrated in Fig. 5-53, employs a pattern with an **annular core print** and a **ring core** for the groove. The core may, if necessary, be reinforced with wire to prevent fracture in handling.

83. Fig. 5-54 illustrates **sweep molding** employed for molding parts whose shape is that of a surface of revolution. In the preliminary process, a base *B* and spindle *S* are well seated in the foundry floor, and the sand filled in and rammed until the excavation approximates the size and shape of the required casting. A sweep holder is then placed on the spindle and the sweep is attached by bolts. The surface of the mold is generated by the profile of the sweep as it is rotated about the spindle. After sweeping, the spindle is removed and the mold patched at the center. The gate is then cut and the mold is ready for pouring. In some molds a cope is placed over the mold after it is swept. Large cast-tooth spur and bevel gears are often sweep-molded by using an indexing arrangement and molding three or four teeth at each indexing operation.

Another form of sweep molding employed on large castings uses a **skeleton pattern** and several strickles or sweeps. Fig. 5-55 shows a casting and a skeleton pattern. The skeleton pattern is obviously cheaper than a solid pattern and a core box. In the first operation, the skeleton pattern is placed on the levelled foundry floor into which several bolts have been set for locating the cope. The skeleton pattern is placed between the bolts and filled and rammed with sand. In the second operation, illustrated in Fig. 5-56, the surface of the sand in the pattern is swept by the mold strickle *M* illustrated in Fig. 5-60. (One side of the sand is shown swept in Fig. 5-56; the other in its rough form after ramming.) This operation completes the sand-filled pattern for the mold. The pattern is sprinkled with parting sand, and the cope is placed over it and filled and rammed. The cope is then removed and the sand pattern swept with the core strickle *C*, Fig. 5-58, to form the core. The skeleton pattern is removed and the cope replaced, forming the completed mold shown in Fig. 5-59.

84. Casting defects may be caused by improper molding, poor design, or careless foundry practice. **Blow holes** are caused by gases which are pocketed in the mold on account of poorly vented molds, or the use of green sand which is too wet. **Sand holes** are caused by loose sand washing into the mold cavity and fusing into the interior or the surface of the casting. Additional facing material, better ramming, or if necessary, the substitution of a dry sand mold for a green sand mold, may prevent this defect. **Scabs** are patches of sand at the upper surface of the casting, which are generally caused by improper venting. **Lifts and shifts** refer to cope or core misplacements. **Cold shuts** are caused

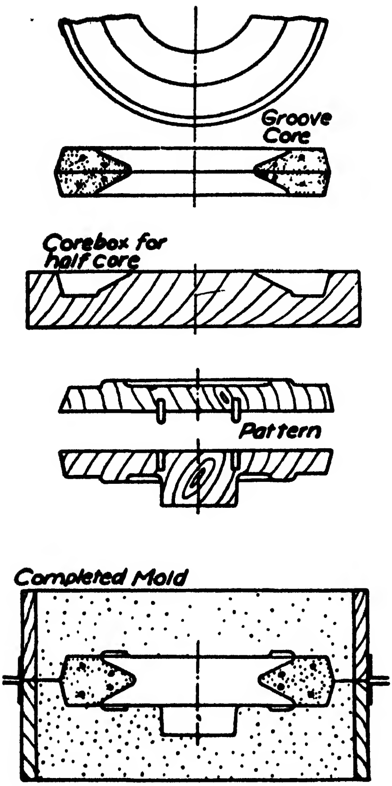


FIG. 5-53. Sheave Molding: Cored Groove.

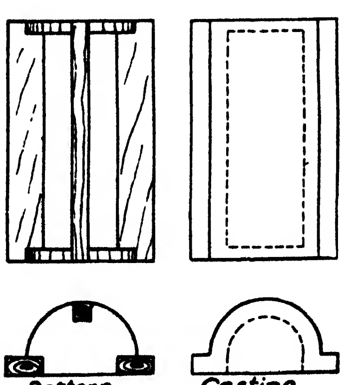


FIG. 5-55. Casting and Skeleton Pattern for Sweep Molding.

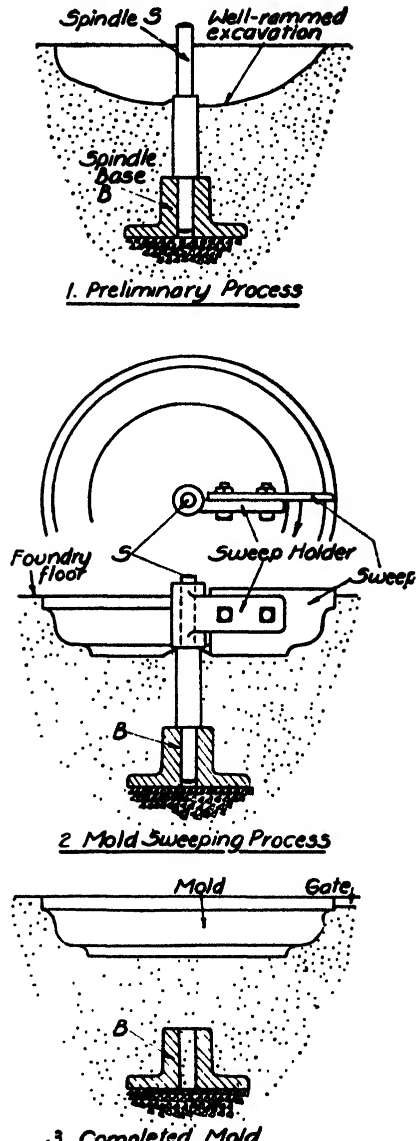


FIG. 5-54. Sweep Molding.

by two streams of metal that are too cold to fuse properly, meeting in the mold. Cold shuts may be remedied by the use of hotter metal or by the redesign of the part so that it will have heavier sections. **Shrinkage**

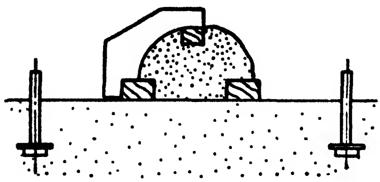


FIG. 5-56. Sweep Molding with a Skeleton Pattern: Operation 2.

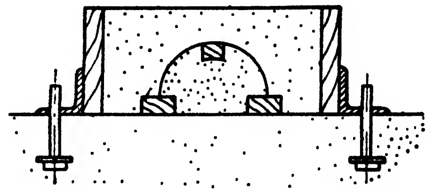


FIG. 5-57. Sweep Molding with a Skeleton Pattern: Operation 3.

cracks may require redesign also. Almost any section, however, no matter how thin, may be properly cast if the mold is correctly gated. A casting is said to be **poured short** when the amount of metal in the

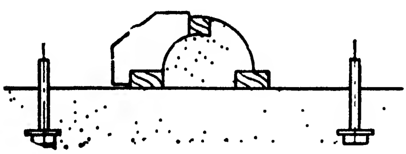


FIG. 5-58. Sweep Molding with a Skeleton Pattern: Operation 4.

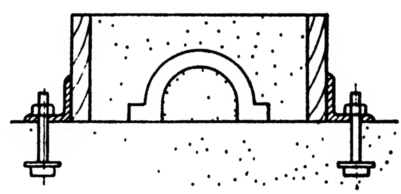


FIG. 5-59. Completed Mold.

ladle was misjudged and the mold was not filled at one pouring.

85. After a casting has been shaken from the mold, the first operation is to cut off the gate and riser sprues and other appendages that do not belong to the casting proper. This may be done by using a hack-saw, by a cutting torch, or in a press known as a sprue-cutter, which has two chisel-shaped cutters which shear the projections from the casting. If the runners and gates are small in comparison to the sprues and the casting itself, the sprues may be knocked off with a hammer.

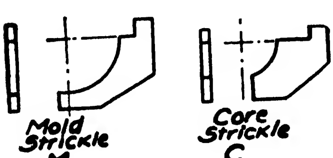


FIG. 5-60. Strickles.

There are several methods of cleaning castings which effectively remove the sand and scale. Castings of uniform size, weighing about fifty pounds or less, are generally cleaned by **tumbling** them in rotating barrels. The tumbling barrel shown in Fig. 5-61 is a square steel shell

with a trunnion attached to each head. The trunnions rotate in bearings and the barrel is driven by gearing and a belt drive. Iron "stars" and shot are included in the barrel with the castings. As the barrel revolves, the castings tumble over and over, cleaning each other within a half hour.

Sand blasting is a very effective method of cleaning castings by using a stream of high-pressure air into which quartz sand or metal abrasive has been introduced. Small castings are cleaned in blasting cabinets; large castings in blasting rooms. A mixing chamber for the sand and air, a nozzle for directing the stream of abrasive on the castings, and media for collecting the abrasive and dust are required. Sand blasting operations are controlled from the outside by an operator who makes observations through a window in the cabinet or room.

Tabor Mfg. Co.

FIG. 5-61. Tumbling Barrel.

Hydraulic cleaning employs streams of water at pressures up to 450 psi directed on castings which are fastened to a revolving table in an enclosed room. Molding sand and cores are easily removed from large castings by this method, and it may be possible in some cases to recover the sand for subsequent use in the foundry.

Pickling is a process of immersing castings in weak acid solutions contained in lead or hard rubber lined tanks. Sulfuric and hydrofluoric acid solutions with concentrations of from 2% to 15% are most frequently used. Pickling is used principally for preparing the surfaces of castings for plating, although it is occasionally used for cleaning fragile castings.

Wire hand brushes and wire brush wheels are also employed for cleaning purposes. Grinding or snagging wheels, on either portable or stationary machines, are used for removing metal and rough edges, particularly parting-line fins, from castings.

CHAPTER 6

FORGING AND ALLIED PROCESSES

86. Forging is the process of shaping heated metal by the **application** of sudden blows or steady pressure, and makes use of the characteristic of **plasticity** of the material. A metal such as steel can be shaped in a cold state but the application of heat lowers the yield point and makes permanent deformation easier. Forging may be done by hand or by machine. Forging by machine involves the use of dies and is generally used in mass-production; hand forging or blacksmithing is employed for small-quantity production and for special work. It is essentially a manually-controlled process even though some machinery such as power hammers and presses are sometimes used.

87. In **hand forging,** the metal is heated in a blacksmith's forge illustrated in Fig. 6-1. The forge consists of an iron fire-pot lined with fire-clay or other refractory material, in which coke is burned by the aid of a flow of air which enters at the bottom of the firepot. In the forge shown, the air is supplied by a hand-operated blower at the left, but motor-driven blowers are often used. The hood over the firepot collects the gases flowing through the fire and controls any smoke or sparks. The forge has a water tank at the right so that work may be cooled. In operation, the work is placed in the firepot and heated to the proper temperature for forging; the smith controls the flow of air by the levers shown beneath the bed of the forge.

A great deal of hand forging is done by **hand hammering** on an **anvil,** Fig. 6-2. Anvils may be made of forged mild steel with a tool steel **face** welded on the body. The anvil is generally bolted or strapped to a wooden base, provided to absorb vibration. The **horn** of the anvil serves for a backing in ring making or for hammering to a curve. **The pritchel hole** in the anvil face is used for bending rods of small diameter, and as a die for hot punching operations. The square or **hardie hole** in the anvil face is used to receive the square shanks of various fittings.

When the smith uses a hammer directly on the metal to be forged, it is either a **ball peen hammer** which has a slightly convex striking face at one end and a hemispherical or ball face at the other, a **cross peen hammer** which has a rounded-vee face that is perpendicular to the handle, or a **straight peen hammer** which has a rounded-vee face

that is parallel to the handle. The work to be forged is generally held with tongs. **The gad tongs** are used for general "pick-up" work, either straight or tapered, the **straight-lip fluted tongs** for square, circular, and hexagonal bar stock, the rivet or **ring tongs** for holding bolts, rivets and other work of circular section, and the **flat tongs** for work of rectangular section. One form of flat tongs has lips at the sides as shown in Fig. 6-5, to prevent the work from slipping sideways. After the work has been gripped between the jaws of the tongs, a ring or coupler is often driven on the handles to eliminate the manual strain of holding them tightly together.

Buffalo Forge Co.

FIG. 6-1. Blacksmith's Forge.

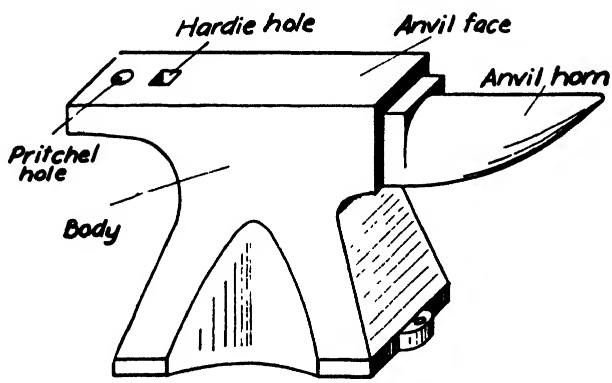


FIG. 6-2. Anvil.

FIG. 6-3. Anvil Fittings.

Blacksmiths' **formers** resemble hammers but are not used as striking tools. The former is placed on the forging and held by the smith, while the upper end of the former is struck by a **sledge** wielded by a helper. **Sledges** are heavy long handled hammers varying in weight from two to twenty-four pounds. Formers may be used in conjunction with some of the anvil fittings of Fig. 6-3, or with a **swage block**, Fig. 6-6, which may be set up on edge as illustrated or laid flat to serve as a die for hole punching.

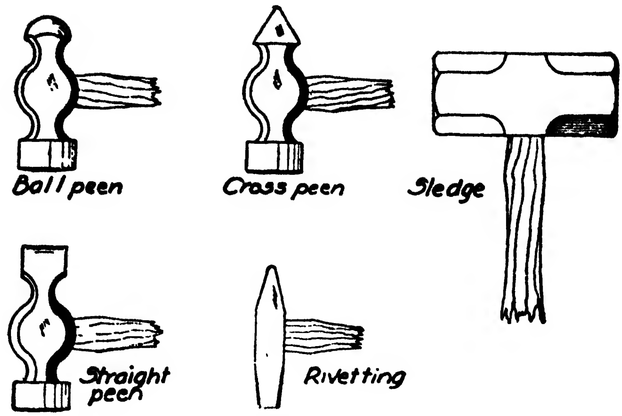


FIG. 6-4. Blacksmiths' and Machinists' Hammers.

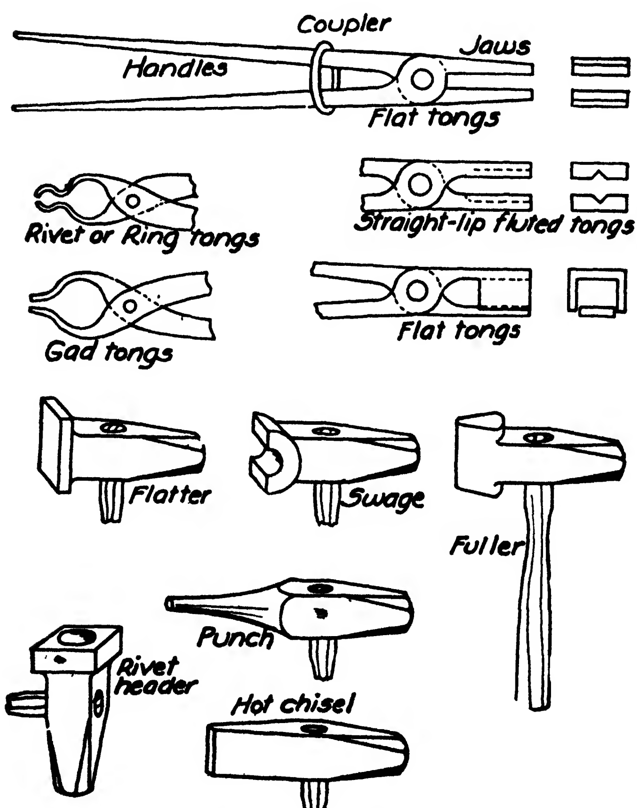


FIG. 6-5. Blacksmiths' Tongs and Formers.

88. Upsetting is the process of increasing the cross-sectional area of a bar at the expense of its length. Fig. 6-7 *A* shows a piece of bar stock; *C* shows the effect of comparatively light hammer blows on a uniformly heated bar, while *D* shows the effect of heavy hammer blows. Local upsets may be obtained as shown at *B* and at *E* by heating only the end or the middle of the bar.

Drawing-down or **swaging** is the process of increasing the length of a bar at the expense of its cross-sectional area. Fig. 6-8 *A, B,* and *C*

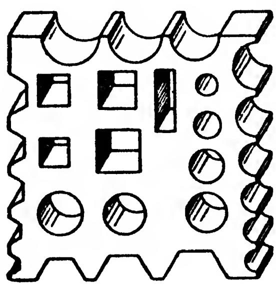


Fig. 6-6. Swage Block.

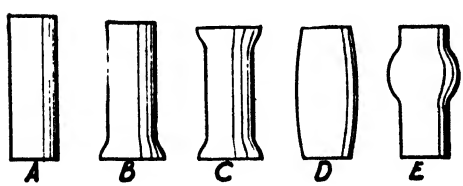


Fig. 6-7. Upsetting Operations.

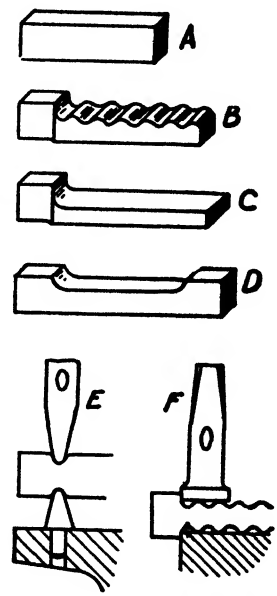


Fig. 6-8. Swaging Operations.

illustrates this operation. *A* represents the original stock; *B* shows the stock after hammering with a straight peen hammer or with a **top fuller** and sledge; and *C* shows the finished forging after the **flatter** has been used. If the swaging operation is performed in this manner, both the length and width of the bar are increased at the expense of the height. If the original width of the stock is to be maintained during the swaging process, it is necessary to turn the bar on its edge and use the flatter between the stages of fullering. **Setting-down,** illustrated at *D*, is a localized drawing-down or swaging operation. Fig. 6-8 *E* shows the process of setting-down both edges of a bar using the top and bottom fuller, and *F* illustrates how the flatter may be used close to a shoulder. The forging

at *D* may be given a circular section by hammering the edges and then using the top and bottom swages.

Bending processes may be classified as angular, Fig. 6-9, or curvilinear, Fig. 6-10. Bending may be done over the edge of the anvil face, over the anvil horn, in special forms such as the swage block edges, or for bar stock, by inserting the end of the bar in the pritchel hole and bending the bar with a wrench or tongs. Fig. 6-10 shows the stages in bending a bar over the horn of the anvil using a hammer. In angular bending over the edge of the anvil face, the outer surface of the angle is subjected to an inherent drawing-down process. A sharp exterior angle such as illustrated at *F*, cannot be obtained without first providing a local upset as at *D*, before bending, to give sufficient material to "work-up" or forge the sharp outer corner.

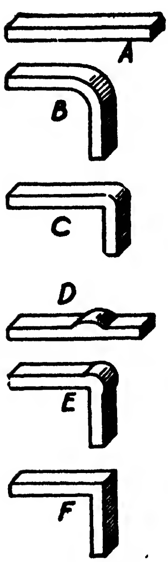


FIG. 6-9. Bending to a Right Angle.

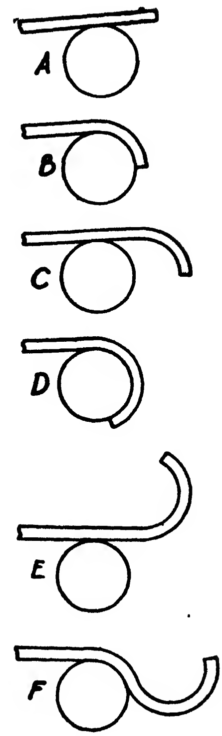


FIG. 6-10. Bending Over the Anvil Horn.

Punching is the process of removing a *slug* of metal, generally cylindrical, by using a **hot punch** over the pritchel hole of the anvil, over a cylindrical die, or over a hole of the correct size in the swage block. Fig. 6-11 shows the stages in **punching a hole**; the illustration at the left shows the work, die, and punch in position; the next shows the punch penetrating about halfway through the work. The work is then turned

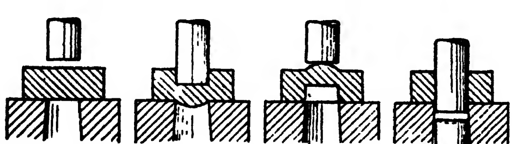


FIG. 6-11. Stages in Punching a Hole.

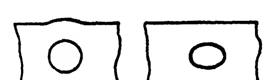


FIG. 6-12. Effect of Hole Punching.

over and the punch driven all the way through. If the hole is punched through from one side only, a *burr* or upset of appreciable size remains on the under side of the work particularly in thick sections. If the hole

in the die is appreciably larger than the diameter of the punch, the punched hole will be tapered. Fig. 6-12 shows the effect of punching a hole in stock of comparatively narrow width. The material bulges under the action of the punch and the sides must be flattened, producing an oval hole, if the work width is to be maintained.

Cutting-out is the process of cutting large holes of various shapes by using a **hot chisel** over a hole in the swage block. It is generally advisable to punch holes to terminate the cuts before doing the actual slitting, so that a subsequent metal fracture will not start at the point where the slitting operation ceases. This precaution is absolutely necessary if the part is to be forged or worked after slitting. Cutting may also be done by placing the work over the hardie and hammering down on it.

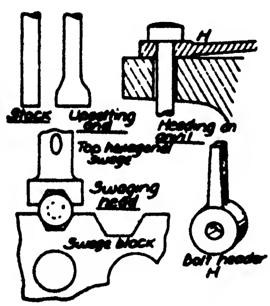


FIG. 6-13. Sequence of Operations in Forging a Hexagonal Head Bolt.

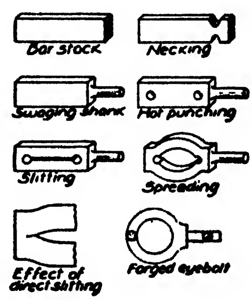
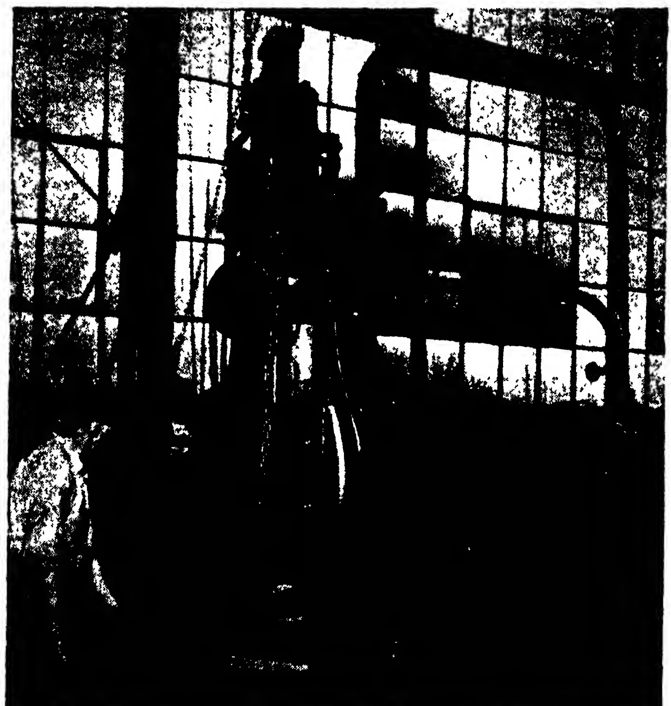


FIG. 6-14. Sequence of Operations in Forging an Eyebolt.

Fig. 6-13 illustrates a method of making **bolt forgings.** The end of the cylindrical stock is upset, and the bar is passed through a **bolt header** so as to form properly the underside and upper end of the head. The hexagonal head may be shaped between a top hexagonal swage and the swage block as illustrated, or the hexagonal head may be hand hammered by the smith. Fig. 6-14 shows the stages in **forging an eyebolt**; in the first operation, the bar is necked and fullered between top and bottom fullers as in Fig. 6-8. The shank is next swaged between top and bottom swages, and two holes for terminating the center cut are punched. The stock is then slit and spread out by the hot chisel. Further spreading is accomplished by hammering the stock over the horn of the anvil. The forging is finished by hammering and rounding the section of the eye.

89. Power hammers are used for unit-production forging operations on work that cannot be feasibly hand hammered, and also on comparatively small work where ~~labor costs may be reduced~~ by their use. There are two

general types of hammers, steam hammers and trip and helve hammers. In the **steam hammer,** steam pressure is exerted on both faces of a vertically reciprocating piston, which is connected to the ram by a piston rod, to raise the ram and also to aid in striking the blow. The steam pressure on the downward stroke imparts additional velocity to the falling weight, and the steam hammer ram will therefore strike a blow whose full rating will be about double that of a gravity ram.



Erie Foundry Co.

FIG. 6-15. Single-frame 800 Pound Steam Hammer Forging Down a 6" Square Billet.

The smaller sizes of hand-controlled steam hammers are usually of the open or **single-frame** type illustrated in Fig. 6-15. The open frame permits the smith to take advantage of the most convenient operating position. In Fig. 6-15, the smith is shown handling the forging with a pair of tongs while a helper operates the controls for the hammer at the direction of the smith. A second helper assists in handling the forging by means of a chain sling. Hammer operations are essentially like hand forging operations. Fig. 6-16 illustrates several of the many hammer tools employed for cutting, fullering and swaging.

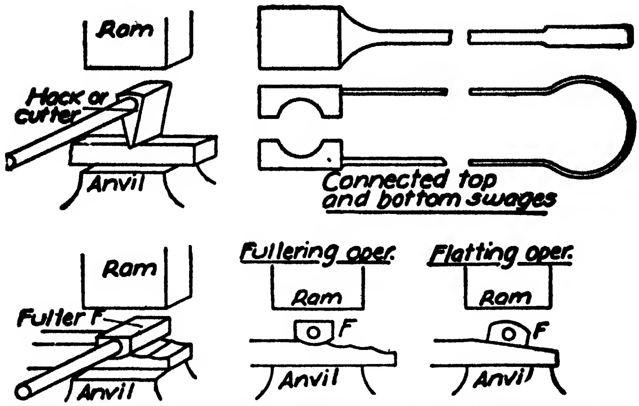


FIG. 6-16. Power Hammer Tools.

Erie Foundry Co.

FIG. 6-17. Double-frame Steam Hammer Used for Forging Alloy Steel Locomotive Connecting Rods.

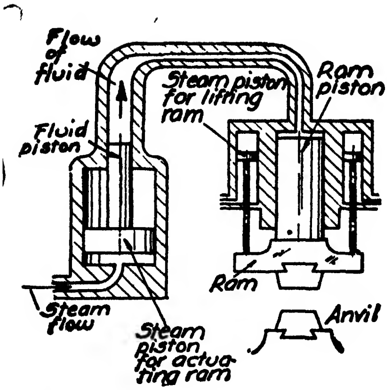


FIG. 6-18. Principle of Operation of Hydraulic Press.

Double-frame steam hammers are used for general forge work of heavy character where the service is too severe for single-frame hammers. Double-frame steam hammers range from 600 to 15,000 pounds in size; single frame hammers from 800 to 6,000 pounds.

A **trip hammer** has a vertically-reciprocating ram that is actuated by a toggle connection driven by a rotating shaft at the top of the hammer. The shaft is driven by a cone clutch which in turn is driven by a second shaft and pulley. The speed of the ram, and the resultant effect of the blow, is deter-

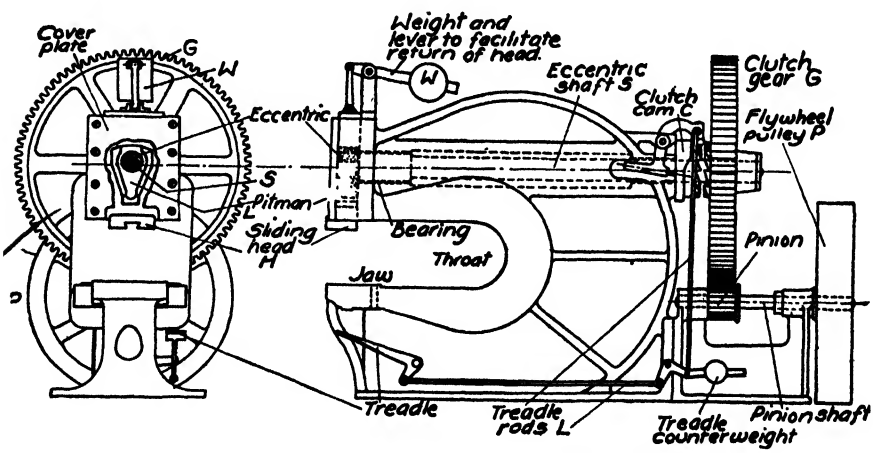


FIG. 6-19. Power-actuated Shear for Structural Fabrication.

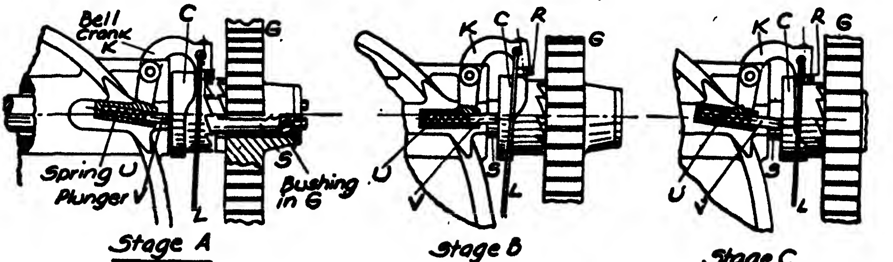


FIG. 6-20. Stages in the Operation of a Shear Clutch Mechanism.

mined by the varying speed of the shaft. Trip hammers are built in sizes from 15 to 500 pounds.

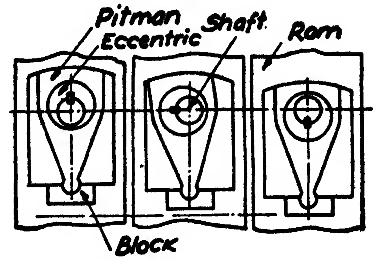
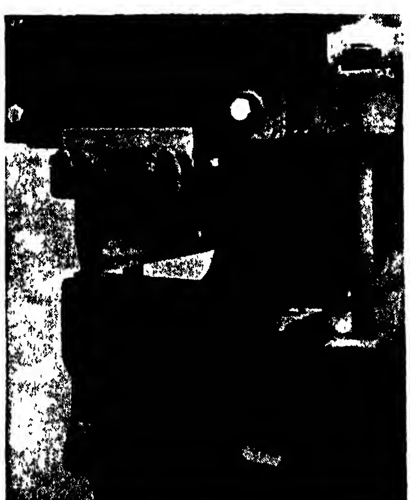


FIG. 6-21. Operation of Eccentric and Pitman of Power-actuated Shear.

Helve hammers are made in the same sizes as trip hammers and are used for similar classifications of work. The helve hammer consists of a horizontal wooden helve, pivoted at one end with a hammer at the other, and a cam or eccentric between the pivot and the hammer. The cam raises the hammer which falls and strikes a blow by the force of gravity. The action of a helve hammer is essentially that of a hand sledge since the wooden helve is somewhat elastic.

Light hammer blows are comparatively superficial in effect, while a heavy more slowly-delivered blow penetrates and influences the material



Cleveland Punch & Shear Works Co.

FIG. 6-22. Plate Shearing Attachment.

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FIG. 6-23. Bar Shearing Attachment.

structure to a much greater extent. This effect is of particular importance in large forgings. Therefore, steam-actuated hydraulic presses are employed. **Hydraulic presses** for forging purposes range in size from 200 to 15,000 tons. Fig. 6-18 shows the principle of operation of a hy-

draulic forging press. A large steam piston actuates a small fluid piston which transmits a very high pressure to the ram piston. At the conclusion of the press stroke, the ram is lifted by two auxiliary steam pistons. Press action is slow in comparison to hammer action, but the reduction in the size of heavy parts is comparatively rapid.

90. Plate and structural fabrication for pressure vessel and structural steel practice are important applications of the cold-working of metals. Fig. 6-19 illustrates a **vertical open-gap punch and shear** that is used for various operations in boiler and structural fabricating shops. The machine consists essentially of a sliding head or ram *H* which has a vertical reciprocation from an eccentric turning in a pitman *L*. The eccentric shaft *S* is keyed to a clutch cam *C*. A clutch gear *G* rotates freely on *S* whenever the jaw clutch teeth are disengaged. *G* is driven by the pinion on the pinion shaft, which in turn is driven by the combination flywheel-pulley *P*.

Fig. 6-20 shows the details of operation of the clutch. Stage *A* shows the eccentric shaft at rest; the bell crank *K* holds the clutch cam *C* out of engagement with the clutch teeth on gear *G* which is constantly rotating on the shaft. When the operator steps on the treadle at the front of the machine, the vertical treadle rod *L* is lifted, which acts on the bell crank *K* and lifts roller *R* clear of the cam on the clutch *C*. This permits the plunger *V* to push the clutch *C* into engagement with clutch *G* as shown at stage *B*. If the operator has released the treadle as soon as the machine is started, the roller drops back to its original position as shown in stage *C*, as soon as the cam strap is clear of *R*. The shaft *S* continues to rotate until the cam strap projection bears against *R*, which causes the cam to disengage the clutch, return it to its original position of stage *A*, and stops the rotation of the shaft and any motion of the ram. The mechanism is arranged so that the ram always stops at the top of its stroke. If successive ram strokes are desired, the operator keeps his foot on the treadle and the ram strikes a blow for every revolution of the shaft. Mechanisms that are similar in principle, although often decidedly different in detail, are used for other types of presses and hammers.

The jaw of the machine is designed to take various attachments for punching and shearing operations. Machines may be obtained with two types of jaws, the plain type shown in Fig. 6-19 which is used primarily for plate work, and the architectural type of jaw shown in Fig. 6-22 and 6-24 which is designed so that structural shapes may have holes punched in both the web and the flanges of the members. The architectural type of jaw is also used for flanged and plate work.

91. Fig. 6-22 shows a **plate shearing attachment** for plate depths that do not exceed the throat depth of the machine, fastened to the architectural type of jaw. The upper shear blade is bolted to a holder which

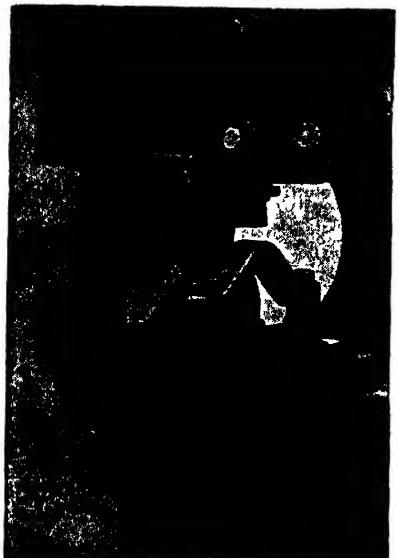

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Fig. 6-24. Angle Shearing Attachment.

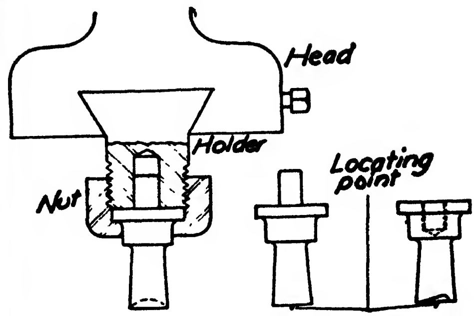

Fig. 6-26. Punch Holder and Punches.

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Fig. 6-25. Punch and Stake, with Stripper.

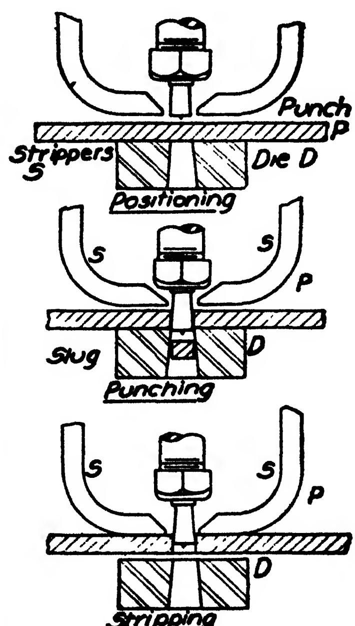
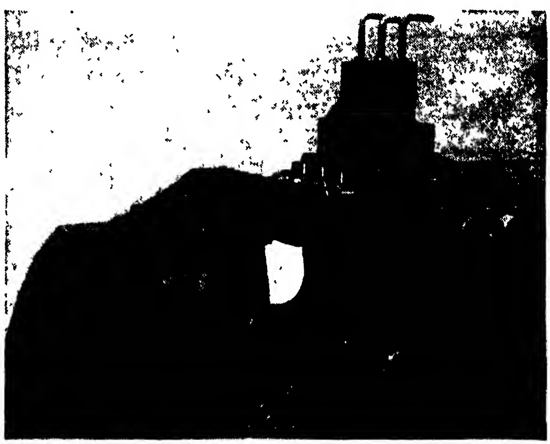


Fig. 6-27. Sequence of Operations in Punching a Hole on a Power-actuated Punch.

fits in the dovetail groove of the sliding head and can be adjusted in a horizontal plane by the square head set screws shown to obtain the proper blade clearance. Fig. 6-23 shows a **bar shearing attachment** which is used for plates and bars of comparatively narrow depth but with a length exceeding the throat depth of the machine. An integral *bar hold-down* is shown at the right, which prevents the work from *jumping* when the shearing operation is performed. Fig. 6-24 shows a similar attachment for **shearing angles.** Coping and notching attachments may also be obtained.

Fig 6-25 shows a **hole punching attachment** fitted to a plain jaw machine. The **stake** or **die** may be of the form shown, which is used



Cleveland Punch & Shear Works Co.

FIG. 6-28. Horizontal Punch with a Triple Hand-gagged Punching Attachment.

for flanged structural sections, or the die may be flat for plate work. Fig. 6-26 shows several types of **punches** and the usual method of fastening the punch in the holder that is held in the ram of the machine. The locating point is employed to assist the operator in aligning the punch with the center of the proposed hole. Punches without locating points are used in connection with cardboard or wooden templates. The shearing type of punch (shown at the right, Fig. 6-26) cuts more efficiently than other types.

Multiple punches, either vertical or horizontal, are extensively employed in structural and plate fabrication. Fig. 6-28 illustrates **a horizontal machine** which is used primarily for punching flanged work and angles, but may also be advantageously employed for punching plate, pipe, and miscellaneous sections. The machine illustrated has a **triple hand-**

gagged punching attachment with a stripper, fitted to an architectural type jaw. With this attachment, the machine can be set up with different

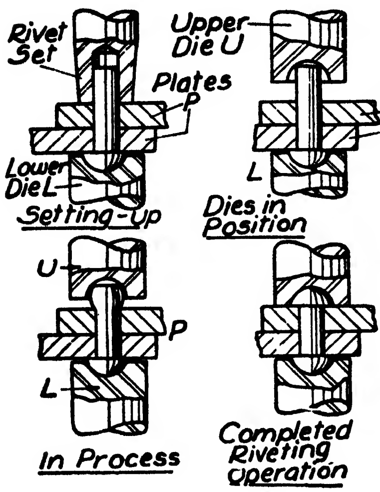


FIG. 6-29. Successive Stages in Riveting.

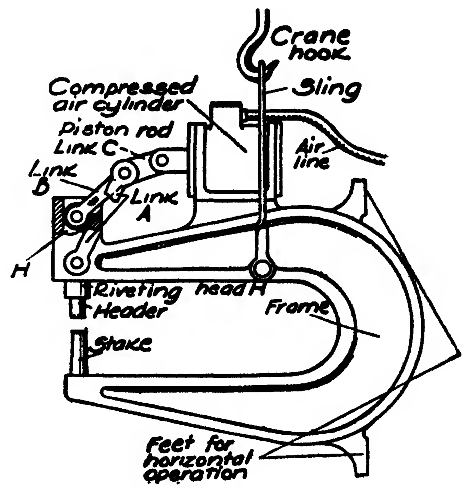


FIG. 6-30. Pneumatic Portable Riveting Machine.

sizes of punches and dies, any of which can be made operative or inoperative by the use of the hand gags shown at the top.

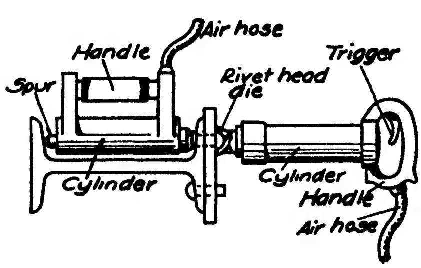


FIG. 6-31. Pneumatic Bucker-up and Riveting Gun, Used in Riveting a Plate to an I Beam.

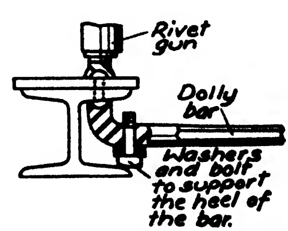


FIG. 6-32. Riveting an H-Beam and Plate Column.

Multiple punches expedite the production rate and are employed wherever feasible. The design of both structural and pressure vessel joints should therefore embody standard repeating rivet pitches whenever possible. Trade catalogs and manuals of steel construction should be consulted for pitches, rivet clearances, etc., in any design project.

92. Riveting is a forging or upsetting process and, except for small or non-ferrous rivets, generally employs heated rivets. As hot rivets are more plastic than cold rivets, the operation is easier and more economical. In addition, the shrinkage of the rivet in cooling tends to produce a tighter joint.

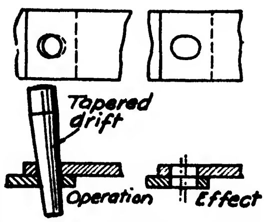


Fig. 6-33. Aligning Rivet Holes by Drifting.

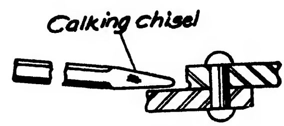


Fig. 6-34. Calking Lap Joint Seams.

Fig. 6-29 shows the successive stages in riveting. Rivets may be driven in the fabricating shop, or in the field in the process of erection. **Shop rivets** may be driven by stationary hammers or hydraulic presses in which the work is brought to the machine, or portable or horseshoe riveters such as those illustrated in Fig. 6-30, may be used where it is easier to bring the machine to the work. In the portable riveter shown,

Fig. 6-35. Calking Inner Butt Joint Seams.

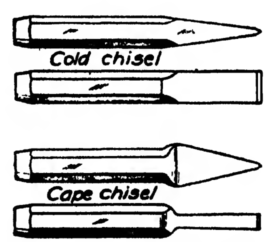


Fig. 6-36. Cold Chisels.

the riveting head is actuated by the link mechanism which is driven by a compressed air piston. The stake serves as a lower die. The portable riveter may be used for vertically riveting as illustrated, or it may be set up on feet and serve for horizontal riveting.

Field riveting may be accomplished by using a rivet head former and sledge, but is generally handled by pneumatic riveting guns such as that illustrated in Fig. 6-31. A backing device of some character must be employed to support the rivet. This may be a pneumatically-actuated

bucker-up illustrated in Fig. 6-31, or a *dolly bar,* Fig. 6-32, either of which must be held by a helper while the rivet gun operator forms the rivet head.

Shop rivets are generally heated in coal or coke fired forges, or in oil or electric heaters. Oil heaters are generally used for field rivets.

In assembling, rivet holes are aligned by drifting or by reaming. **Drifting** has a tendency to elongate the holes and injure the edges of the metal. **Reaming,** which is described in Chapter 10, is therefore generally preferred for alignment purposes.

Calking is the process of sealing joints that are subjected to pressure, and helps to guard against leakage. Calking is done by special chisels as indicated in Fig. 6-34 and Fig. 6-35. In some instances welding is substituted to form a seal along the joint edge even though the joint is held by rivets. Calking is most effective when the joint is designed so that the rivets are close to the calked edge.

Fig. 6-36 illustrates two forms of **cold chisels.** The plain chisel is used for chipping metal, cutting off rivet heads when a rivet is to be removed, and like applications. The cape chisel is generally used for cutting grooves in metal.

CHAPTER 7

SHEET METAL WORKING PROCESSES

93. Many manufactured articles are made from **sheet metal.** Such articles are usually lighter in weight and are often less expensive than castings or forgings. Such important parts as pipe, elbows, transitions, hoppers and guards for gears, etc., may be made of sheet iron and steel, galvanized iron, copper, aluminum, or brass.

The shape to which the sheet material is cut while in the flat state is called the stretch-out or **blank.** The drawing which gives the size and shape of the blank is called the **development.** In many cases the blank is laid out directly by prick-punching through the corners of the development on the drawing; in other instances, where more than one blank is required, a **pattern** or **template** of sheet metal or thin wood is made from the development, and the outline of the blank is scribed on the sheet by following the outline of the pattern.

The blank is cut to the proper shape from the sheet material, and is folded, curved, or stretched until it assumes the desired form. The edges that meet are then joined by seaming, soldering, or riveting, or by a combination of these methods. Fig. 7-1 shows a four-piece sheet metal elbow, the mode of development, and the selection of adjacent developments so as to effect the maximum economy of material. Metal thickness need not be considered in drawing the development unless the material is thicker than 1/32". In such a case, allowance must be made for the resulting shrinkage when the sheet material is bent or curved. In cylindrical objects, for example, this allowance may be taken as from three to four times the thickness of the metal and distributed over the length of the development.

Plane-faced objects, cylinders, and cones can be accurately developed; warped and double-curved surfaces, such as helicoids and spheres, cannot be developed but the surfaces may be approximated in shape by triangulation, and can then be stretched by subsequent operations in dies to give satisfactory results.

94. Hand operations will probably always be necessary in sheet metal fabrication. Fig. 7-2 shows a sheet metal worker's bench with some representative hand tools. **Snips** are universal and indispensable hand cutting tools. Two sizes of snips are shown lying on the bench, and a pair of bench shears is shown standing at the back of the bench. Straight snips may be used for straight or notching cuts; circle snips have curved

jaws for cutting circular arcs and other curves. **Bench shears** are heavy duty sheet metal cutting tools in which the jaws and handles are

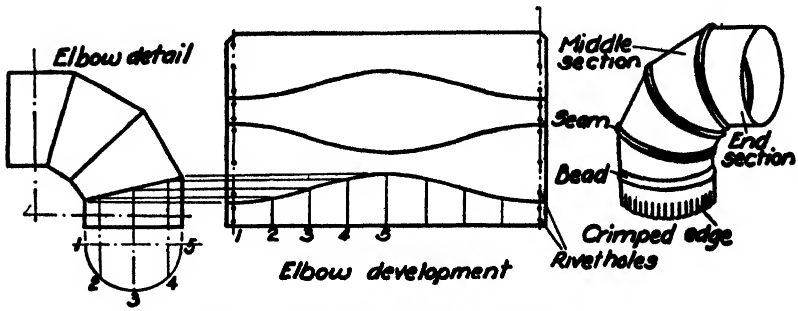


FIG. 7-1. Sheet Metal Four-piece Elbow.

longer than in snips. The bent shank on the handle at the left can be held in a hole in the bench. The other shank limits the motion of the handle and provides clearance for the operator's fingers in the closed position

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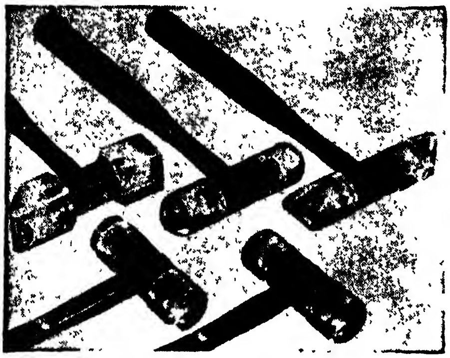
FIG. 7-2. Setting a Seam on a Sheet Metal Box.

Stakes are the anvils of the sheet metal worker. Such sheet metal operations as tube and taper forming, flanging, seaming, and rivetting may be performed with their aid. Most stakes have squared shanks to fit holes

in the bench. Two of the many varieties of stakes are shown in Fig. 7-2. The stake at the right is known as a *teakettle stake,* and has replacable heads for seaming operations. The stake at the left is a *blow-horn stake,* being used for shaping abrupt tapers on the broad end, or taper tubes on the slender horn at the rear.



Bruce Lindsay & Stanley Tools

FIG. 7-3. Soft-face Hammers.

Ball peen, crosspeen, and **riveting hammers** are used by sheet metal workers. **Raising hammers** have convex faces and are used for producing concave or convex formations in sheet metal by a series of blows. In this operation the metal is placed on a concave hardwood block called a **raising block. Soft-face hammers,** such as the plastic tipped hammers of Fig. 7-3 and the hickory mallet of Fig. 7-2, are used when hard-faced hammers would deface the work.

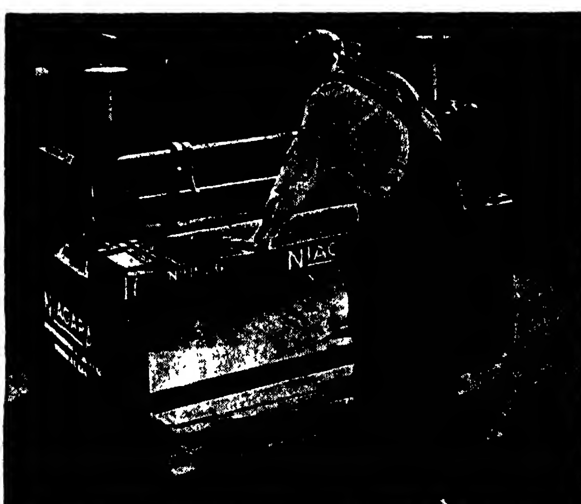


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FIG. 7-4. Power Squaring Shears.

Other tools shown in Fig. 7-2 include two squares; a grooving tool (between the snips) which is used for flattening and offsetting folded

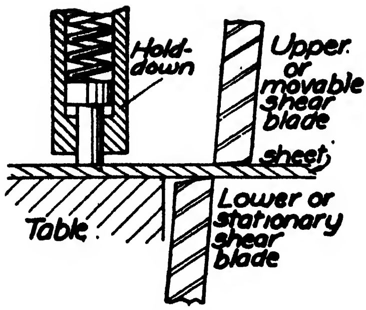

FIG. 7-5. Squaring Shear Principles.

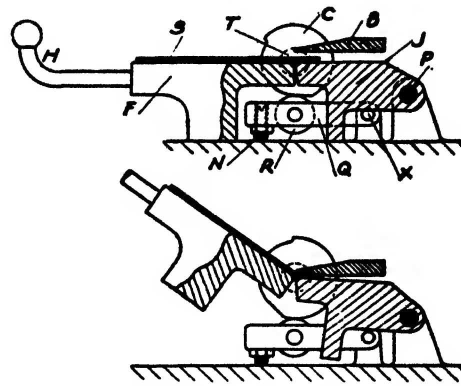

FIG. 7-6. Hand-actuated Bar Folder.

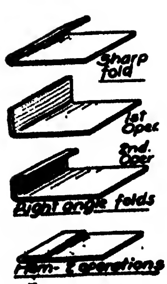

FIG. 7-7. Sheet Metal Folds.

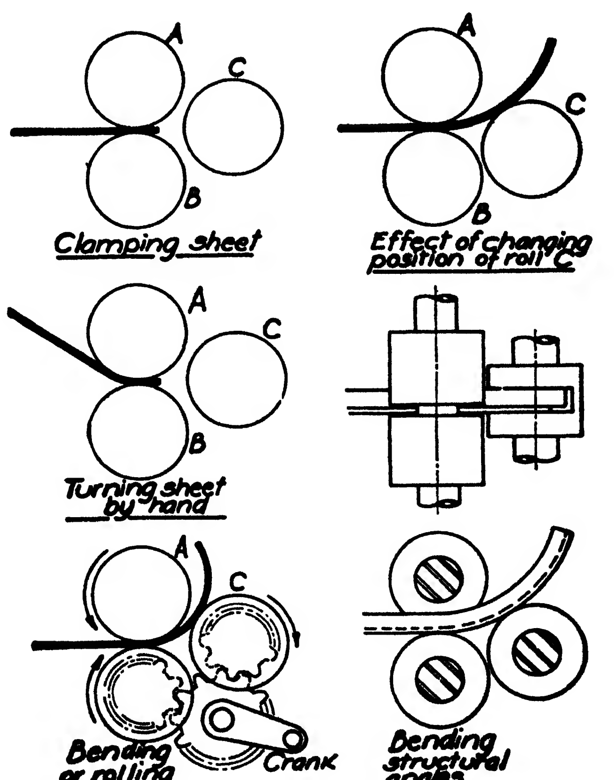

FIG. 7-8. Bending Roll Principles.

edges to make a lock seam; a hollow punch for punching round holes in light sheet metal, which should be used against a slab of lead; and a C-clamp.

95. A variety of standard machinery is used in sheet metal fabrication to facilitate production, secure a better product, and minimize fatigue of the operator. Power actuated machinery is extensively used but many shops obtain excellent results by the use of hand or foot operated shears, folders, and rotary seaming machines.

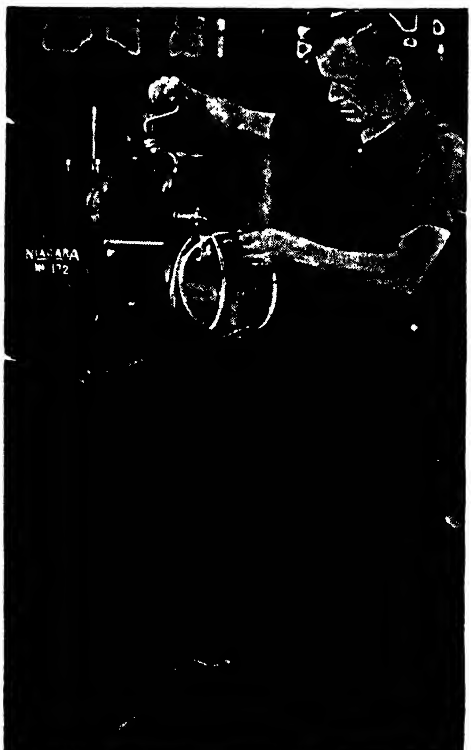

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FIG. 7-9. Rotary Combination Edging Machine for Sheet Metal.

Foot or power actuated squaring shears are used to resquare plates that have been roughly cut on mill shears and to shear plates into strips, trim edges, and cut square, rectangular, or other straight-sided blanks. Fig. 7-4 illustrates a shear on which plates of any size up to the nominal cutting length of the shear can be passed between the housings from front to back; the cut can therefore be made at any distance from the edge. The gap in the housings makes it possible to cut or split plates longer than the shear blade but the maximum width of a long strip is limited by the depth of the gap. After the first cut, the plate is slid to the right for the second cut. A slitting gage assures the alignment and continuity of the successive cuts.

The upper shear blade is set at an angle so that cutting begins at the right and continues across the edge of the shear. In operation, the sheet to be cut is moved forward on the bed of the machine until the desired line of cut is aligned with the cutting edge of the knives. When the foot treadle is depressed, the holddown immediately and automatically clamps the plate and the shear knife makes one cutting stroke. At the conclusion of the stroke, both holddown and shear raise and stop at the highest point of the stroke. If, however, the treadle is kept depressed, the motion of

the upper knife will be continuous, accompanied by properly timed movements of the holddown.

Machines of this type are used primarily for cutting sheet metal but are also used for shearing other sheet materials such as fiber, asbestos, and wall-board.

96. Folders and brakes are machines used for bending or folding sheet metal to an angle or lock. Folders are employed for folds of limited width; brakes have unobstructed openings from front to back and are

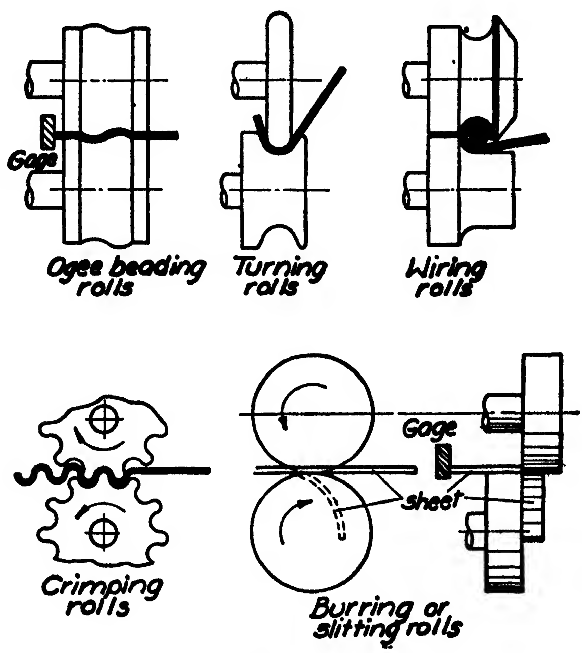


FIG. 7-10. Sheet Metal Rolling Processes.

adapted to folds of unlimited width. Brake operations will be described in Chapter 20.

Fig. 7-6 illustrates the principle of operation of a hand-actuated **bar folder.** The sheet S is placed on the folding bar F which is rigidly pivoted to the jaw J with one edge against a stop or gage (which is not shown in the illustration). The jaw is pivoted to the machine frame at P, and the folding blade B is rigidly fastened to the frame. The cam C is fastened to F and turns with it. A cam roller R is carried by a shoe Q which is pivoted at X and supported at N by a locked set screw so that it can be adjusted for various sheet thicknesses.

When the machine is in the open or starting position, the low part of the cam C is in contact with the cam roller R. As the operating handle H is lifted, the folding bar F turns on trunnions T and rotates the cam C, which rolls on cam roller R and thereby raises the folding bar F and jaw J. This action causes the jaw to clamp the sheet between it and the blade B. A continued motion of the operating handle turns bar F and thereby forms the bend, while the cam maintains a constant clamping pressure on the sheet.

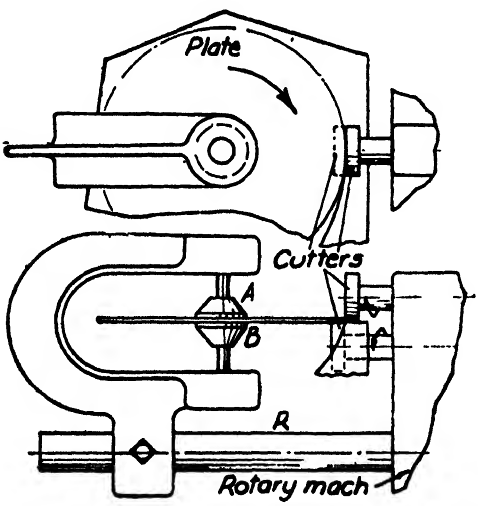


FIG. 7-11. Circle-cutting Attachment for Rotary Shear.

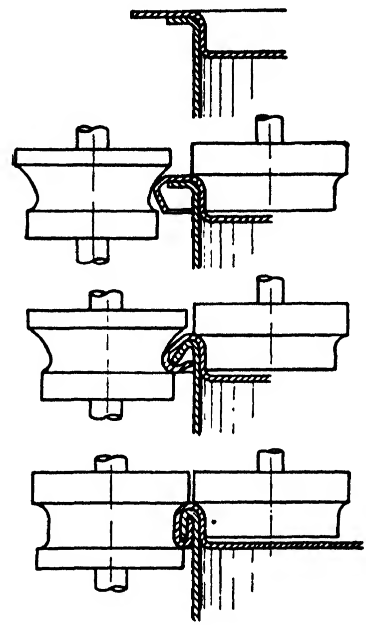


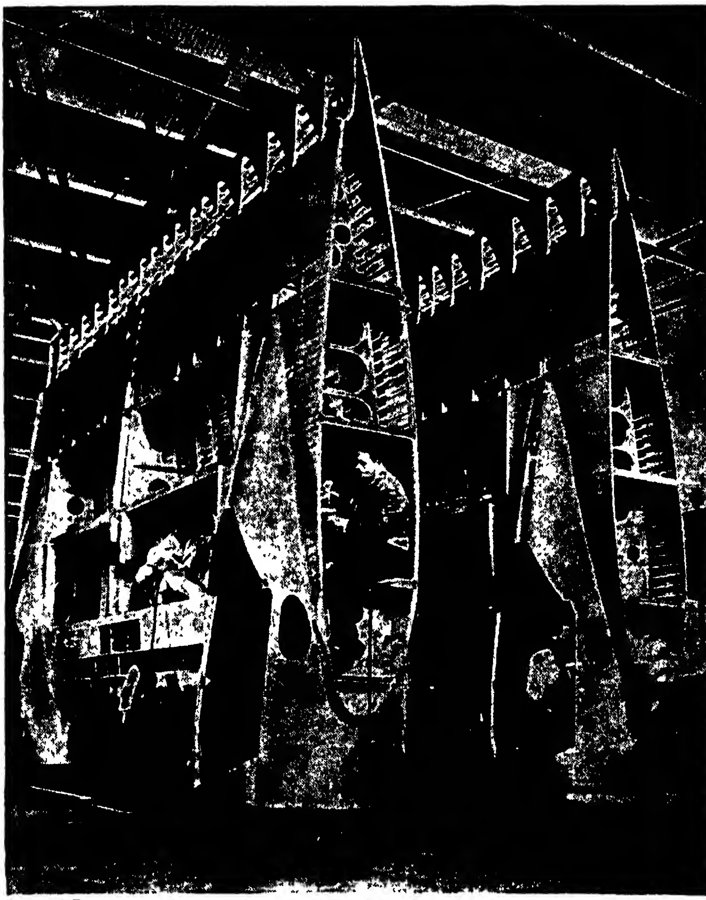
FIG. 7-12. Double-seaming the Edge and Top of a Sheet Metal Container.

Power actuated folders operate on essentially the same principle, and are desirable when quantities of duplicate work are to be done. Both hands of the operator are free to handle the work and production can thereby be increased.

Fig. 7-7 shows a few of the many varieties of folds that may be produced with either hand or power actuated folders. The sharp fold is made by turning the folding bar through an angle of almost 180°; the hem is made by pressing or seaming a sharp fold.

97. Roll forming machines are used to curve flat sheets of metal into pipe or other cylindrical formations. Fig. 7-8 illustrates the principle

of operation of a machine with three cylindrical rolls, *A, B,* and *C,* of which two rolls, *B* and *C* are hand or power actuated. Roll *A* is adjustable vertically to clamp the sheet at the beginning of the bending operation; rear roll *C* is adjustable vertically to produce the required degree of curva-



From "Riveting Aluminum" Aluminum Co. of America

FIG. 7-13. Riveting Center Wing Section of Modern Aluminum Aircraft with Electric Portable Rivetting Machine.

ture. In hand-operated machines, the sheet is placed between rolls *A* and *B* and roll *A* is adjusted to clamp the sheet. The sheet is then turned up in front in order to give it an initial curvature so that it will pass over the top of roll *C*. Rolls *B* and *C* are then rotated, causing *A* to roll with the sheet, which encircles the upper roll as it is formed.

Slip roll forming machines have an upper roll *A* which is pivoted at one end so that the other end may be lifted or swung clear of the machine to permit small pipe encircling the upper roll to be withdrawn in an axial direction. Plain roll forming machines do not have this feature and it is therefore necessary, when forming small cylinders which encircle the upper roll, to spring the edges of the pipe sufficiently far apart to permit removal from the machine.

Rolls are generally provided with a series of grooves at one end to permit wire forming without deformation of the wire section.

98. Hand and power actuated **rotary machines** are used for rolling formations in sheet metal. The contours produced are governed by the shape of the rolls between which the metal passes. The rolls may operate

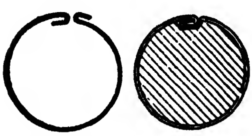


FIG. 7-14. Lock Seam.

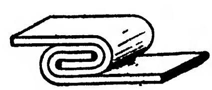


FIG. 7-15. Double Lock Seam.

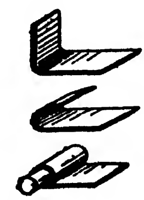


FIG. 7-16. Sequence of Wiring Operations.

at the edge or at some distance from it. Fig. 7-9 shows a motor-driven machine for edging sheet metal elbow sections. The machine consists essentially of two power driven rolls that rotate in opposite directions. The upper roll is adjustable vertically for different thickness of sheet metal as illustrated.

Various types of rolls can be employed for edging flat sheets or sheet metal pipe. **Crimping rolls** are used to crimp or corrugate the edges of pipe to permit easy assembly. **Ogee beading rolls** are used to roll a reverse or ogee bend or bead in plate and pipe. **Turning rolls** are used to turn the edges of sheet cylinders or plate preparatory to wiring or seaming operations. **Burring and slitting rolls** are used for cutting or for trimming the edges of cylinders and sheets. Fig. 7-11 illustrates the essential features of a **circle cutting attachment** that may be applied to rotary edging machines. The plate to be sheared is clamped between two discs *A* and *B* which are free to rotate about their axis. The distance from the disc axis to the edge of the slitting cutters determines the radius of the circle cut. The frame of the attachment may be adjusted on the supporting bar *R* for various radii. **Flanging rolls** for turning

the edges of circle sections may also be employed in connection with this attachment.

99. Hydraulically-actuated automatic machinery for flanging, beading, and corrugating steel drums for oil and similar materials are extensively used and will afford a product of five completed drum bodies per minute. Automatic beading attachments to insert a head in each end of the drum, and automatic seamers to seal the heads to the bodies, may also be incorporated in this type of machinery.

CHAPTER 8

MACHINING AND SURFACE FINISHING PRINCIPLES

100. Material removal, dimensional accuracy, and **surface refinement** or finish are the three primary considerations in all **machining processes.** In some instances one of these is essential and the others must be disregarded; in other cases all three must be considered. For example, in cutting threads on ordinary studs and screws where a precise fit in the threaded hole is not particularly important, machining processes to remove the maximum amount of metal in a given time consistent with a reasonable degree of accuracy may be employed. In a second instance, when parts are polished preparatory to a plating operation, the surface finish must be good although very little material is removed, and some dimensional accuracy may be sacrificed. In a third instance, however, when gages and commercial measuring equipment are manufactured, dimensional accuracy is the primary consideration. A high degree of surface finish is also necessary so that dimensional accuracy can be determined and maintained. Metal removal is definitely subordinate to these first two considerations, but is still important because commercial gages must be manufactured as economically as possible.

101. Material removal is accomplished by hand or machine-actuated cutting tools. The stages in the action of a cutting tool are illustrated in Fig. 8-1 and 8-2. Fig. 8-1 shows a block of wood that is cut by a hatchet. In the first stage the cutting edge of the hatchet compresses the material under it. (The edge of the hatchet is shown rounded because no edge, no matter how carefully sharpened or finished, is ever perfectly sharp.) The compression in the material reaches the point of failure and the wood then splits, completing the cut as shown in the second stage. Fig. 8-2 illustrates a similar action in metal cutting. The first illustration shows an initial compression of the material at the tool edge; the second shows the splitting of the metal along a cleavage plane after the compressive limit of the material directly under the tool edge has been exceeded. The material removed is known as the **chip.**

The work expended in metal cutting consists of tearing the chip from the metal and overcoming the frictional resistance engendered by the chip passing over the surface of the tool as it curls or crumples. The energy expended depends upon the chip area cut, the machineability of the material, and the contour and finish of the cutting tool.

Fig. 8-3 illustrates the action of a razor and a wood chisel. Angle C represents the relief angle which is introduced to prevent the cutting tool from dragging or rubbing on the cut surface. This angle is generally made as small as possible to prevent the cutting tool from digging into the surface. Angle L represents the lip angle which in general should be as small as possible. The resistance of the cutting edge to fracture, however, becomes less as the lip angle is decreased; if a razor is used for cutting wood, the operation is performed with a minimum application of power, but the delicate edge of the razor soon fractures or breaks down.

Fig. 8-4 illustrates three types of metal-cutting tools in which C represents the relief angle, and R the rake angle which is the angle between the tool face and a perpendicular to the surface being cut. By contrast with the wood-cutting operations, it may be seen that the lip angle for metal cutting is much greater than for wood-cutting and the rake angle is con-

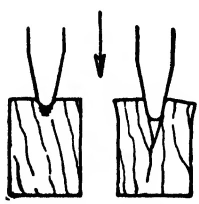


Fig. 8-1. Stages in Wood Cutting.

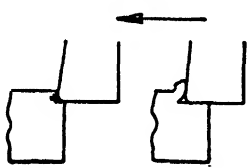


Fig. 8-2. Stages in Metal Cutting.

Fig. 8-3. Wood Cutting with a Razor and a Chisel.

siderably less. A zero rake angle is employed for brittle materials such as cast iron, while materials such as copper are often cut with a negative rake angle since the tough character of the material has a tendency to cause the cutting edge to *"dig in"* and tear or spoil the cut surface.

102. Fig. 8-5 shows a **reciprocating tool** for metal cutting. The tool moves along a straight line and cuts on the forward stroke only. The cutting action takes place in two planes and therefore multiple relief and rake angles are provided to facilitate the removal of the chip.

On each cutting stroke, the tool removes a section of metal whose cross-sectional area is determined by the **depth of cut** and by the **feed per stroke** or distance that the tool point moves to the right at each cutting stroke. The **feed** is generally stated either as so many thousandths of an inch per cutting stroke or as so many inches per minute. In the case of reciprocating tools, the **cutting speed** is given as so many inches or feet per minute exclusive of the idle return stroke. Both the speed and the feed are largely dependent upon the power limitations of the machine tool employed, and upon the machineability of the material being cut. In addition, the selection of a suitable cutting speed depends upon

the hardness of the cutting tool and its resistance to high temperature, while the feed is governed by the strength and shape of the tool.

103. Fig. 8-6 shows how the cutting tool of Fig. 8-4 is employed for a turning operation. The work rotates about its axis and the cutting tool is fed parallel to this axis. The relative position of the tool point and the work axis affects the rake and clearance angles. When the tool point is set above the axis, the actual clearance is decreased and the rake angle is increased resulting in a wedging or true cutting action; when the tool point is set below the work axis, with increased clearance, the rake angle may actually become negative, and a scraping or crumbling action results.

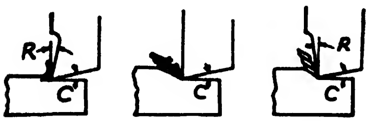


FIG. 8-4. Metal Cutting.

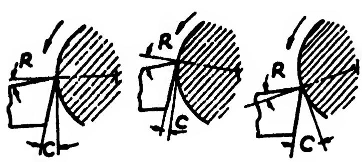


FIG. 8-6. Effect of Tool Position in Turning.

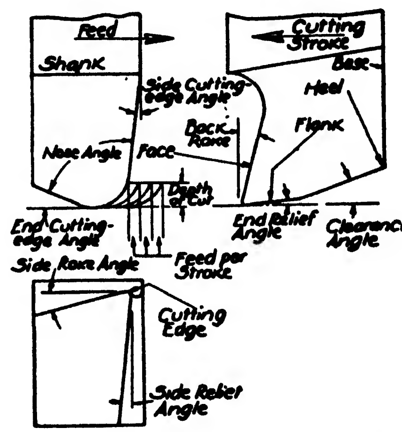


FIG. 8-5. Metal Cutting Tool Nomenclature.

Formed tools must be set on-center since the contour of the cut is affected by any change in the relation between the axis and the tool point.

104. There are two distinct methods of producing surfaces by cutting tools: forming and generating. In **forming,** the shape of the surface is a replica of the shape of the cutting tool. In **generating,** the shape of the surface depends upon the directions of motion of the tool with relation to the work and is practically independent of the tool shape. The distinction between the two methods is illustrated in Fig. 8-7. **In generating a cylinder,** the work rotates about an axis and the cutting tool moves in a direction parallel to the axis. The precision of the cylindrical surface is therefore dependent upon the accuracy of the machine tool in controlling the motion of the cutter. **In forming a cylinder,** the work is stationary and the cutting tool moves in the direction of the axis of the cylinder, forming one-half of the cylindrical surface at one stroke. The

shape of the surface is therefore dependent upon the accuracy of the tool shape.

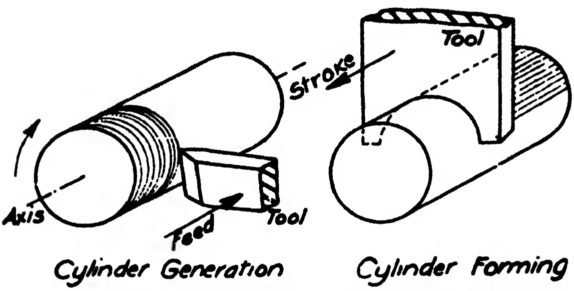


FIG. 8-7. Generating and Forming a Cylindrical Surface.

Plane, cylindrical, conical, involute, and helicoidal surfaces are among the most important generated shapes. Formed surfaces may have almost any shape.

Generated surfaces are ordinarily easier to produce than formed surfaces and can be finished to a higher degree of precision particularly when the work is so hard that abrasive cutting materials must be employed.

105. Fig. 8-8 illustrates the action of **rotating multi-toothed cutters**, in which the work is held below the cutter arbor (or shaft upon which the cutter is mounted). There are two methods of cutting: **cutting up**, and cutting down or **climb cutting**. In **cutting-up action**, each tooth of the cutter takes a wedge-shaped chip whose initial thickness is zero and whose final thickness depends upon the rate of feed. The cutting action has a tendency to lift the work from the surface on which it is placed, and work must therefore be restrained vertically as well as longitudinally.

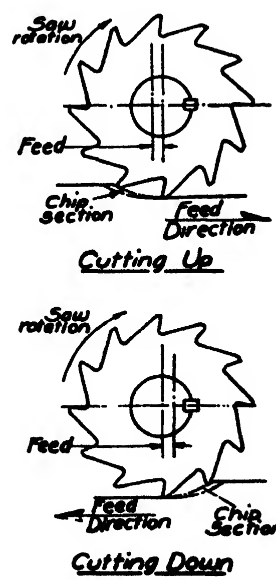


FIG. 8-8. Rotating Cutter Action.

Climb cutting produces a chip of maximum thickness at the beginning and zero thickness at the end of the cut. As a result, the machined surface has a better finish than can be obtained by cutting up. In climb cutting, each tooth must take an appreciable "bite" as it comes in contact with the work and cannot slide or skid over the surface. There is, there-

fore, less tendency for the cutter and work to vibrate and chatter than in cutting up. In climb cutting, the action also tends to hold the work down and the process is thereby adapted to delicate or fragile parts that cannot be tightly clamped.

Climb cutting has one major disadvantage. The cutting action has a tendency to draw the work in towards the cutter. This tendency is manifested when a heavy feed is used or when the machine is not sufficiently rigid or powerful for the size of the cut. In such a case, the cutter tends to climb over the work and may thus ruin the work, the cutter, and possibly the machine. For this reason climb cutting is not employed for medium and heavy duty service, particularly where comparatively old machine tools are used.

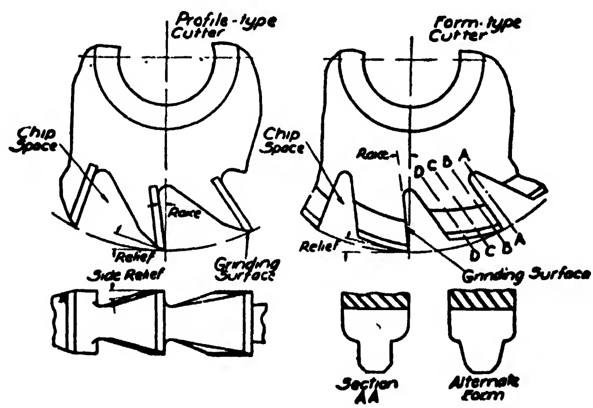


FIG. 8-9. Rotating Cutter Principles.

106. Fig. 8-9 illustrates the difference between profile-type and form-type multi-toothed cutters. The **profile-type cutter** is sharpened by grinding along the indicated edge, and is therefore limited to straight-line cutting edges. The **form-type cutter** is sharpened by grinding the face of each tooth. Since the teeth are of unvarying shape—sections *BB*, *CC*, and *DD* being exact replicas of section *AA*—these cutters may be ground without change of form if an equal amount is removed from each tooth of the cutter.

The profile-type cutter is the more efficient of the two types since it has considerably more chip space between the teeth. It is also possible to provide side relief for this type. The form-type cutter shown has no side relief since this would affect the tooth shape after grinding. Sometimes a change in the design of the work will permit an alteration in the cutter

profile, as illustrated in the alternate form, thus permitting clearance or side relief.

If, in Fig. 8-3, the razor edge moves perpendicular to the plane of the paper simultaneously with the direction indicated, the minute serrations of the cutting edge, on account of their saw-like action, aid in the removal of the chip. This principle is employed in rotating cutters by making the tooth edges helical instead of straight lines parallel to the cutter axis. Some of the shock of tooth contact is eliminated and a cleaner, smoother finish generally results.

107. The action of an abrasive or grinding wheel is similar to that of a rotating cutter. An **abrasive wheel** is composed of sharp particles of abrasive held in a bonding material which permits the grains to be torn loose as they become dull. The abrasive grains cut very small chips from the work in the same manner that a rotating cutter does, though on a much smaller scale.

Abrasive processes are generally employed for metal removal when the work is so hard that it cannot be conveniently machined with metal cutting tools. Abrasive processes are also extensively used for surface refinement and finishing.

108. All machined or cut surfaces are irregular to some extent for several reasons. In the first place, metals are not absolutely homogeneous; some portions may be harder than others and may cause the cutting tool to deflect or spring away from the cut surface. Second, most metals are of crystalline structure. When metal is cut, some of the crystals are sheared through, while others are torn loose from the adjoining crystals. Third, minute particles or chips may cling to the edge of the tool and scratch the surface of the work. Instead of being smooth, therefore, machined surfaces are composed of small serrations or scratches whose depth may vary from one to one thousand or more micro-inches.

The heat generated by cutting is often very great and may cause a decided change in the nature of the metal adjacent to the cut surface. Under the influence of this heat, some of the loose metal particles and the serrated edges may be welded or combined into an amorphous metal substance known as *smear* metal.

Smear metal may exist on any cut surface and is of distinctly different character than the parent metal.

In many instances, where surfaces are machined to provide clearance or to serve as a seat or brace for brackets or frames, an ordinary cut surface is satisfactory. On the other hand, if the surface must be resistant to wear or abrasion as in a bearing, or if it is employed as a reference in precise measurement as in gages, ordinary cutting processes are not adequate. The

surface serrations and the smear metal have no appreciable resistance to abrasion, and may prevent the formation of an oil film if the surface is used as a bearing. Both smear metal and surface serrations must be removed from the contact surfaces of measuring equipment, not only because of the rapid wear that may be expected in service, but also because accurate dimensional determination is difficult if not impossible when surfaces of such character are used as a basis for measurement.

109. It is the function of **finishing processes** to remove or smooth down the irregularities or serrations on a machined surface, and to eliminate the smear metal that results from previous machining operations.

CHAPTER 9

WOODWORKING PROCESSES

110. Woodworking is a cutting process performed with the aid of both hand and mechanically-actuated tools. Hand tools may be classified as layout or measuring tools and as cutting tools.

111. Handsaws are used for bringing stock to size, for roughing out grooves, and for numerous other purposes. There are two important types of hand saw teeth: cross-cut saw teeth, which are pointed and are employed for cutting across grain; and ripsaw teeth, which have chisel edges and are used for cutting with the grain of the wood. All saws should have some *"set,"* by which is meant the distance that the points project beyond the sides of the saw blade. **Ripsaw** teeth have more set than cross-cut saw teeth to eliminate the possibility of the blade sticking in the groove or kerf, but in general as little "set" as possible for free cutting is desirable. A **cross-cut saw** may be used for sawing with the grain but a ripsaw leaves a very ragged edge when used for cutting across the grain.

The **backsaw** is a fine-tooth cross-cut saw with a thin blade and is designed for accurate work. As its name indicates, it is reinforced with a heavy steel rib. It is illustrated in Fig. 9-2, which shows a **mitre box** consisting of a frame and an adjustable quadrant with guides for the saw. The quadrant may be swung to an angle of 60° on each side of a centerline perpendicular to the back of the frame; the mitre box may therefore be employed to cut bevels from 30° to 90° on stock. The *"broken-out insert"* on the piece of molding in the figure illustrates an adjustable spur in the back of the frame which keeps the work from slipping while it is being sawed.

A **compass saw** is a cross-cut saw with a narrow tapered blade, and is used to cut curves and circles after a preliminary hole has been bored in the stock. A **coping saw** has a C-shaped steel frame and a very narrow blade and is used for cutting curves in thin stock.

112. Chisels are cutting tools used in joint construction and in fitting and shaping. Fig. 9-3 illustrates a beveled face butt chisel which has a plastic handle and a steel cap so that it may be used with both hands, or held in one hand and struck with a mallet. Chisels are used to cut mortises, grooves, bevels and chamfers. For mortise cutting, a chisel with a thick narrow blade of rectangular section is generally employed to prevent breakage when prying out chips from the mortise.

Gouges are chisels of circular section as illustrated in Fig. 9-4. Outside bevel gouges are used for wood-turning roughing cuts and for cutting flutes with spherical ends (blind flutes). Inside bevel gouges are

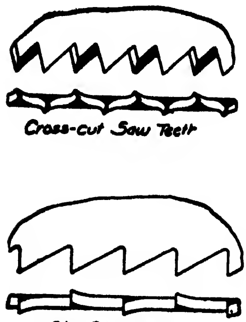


FIG. 9-1. Types of Hand Saw Teeth.

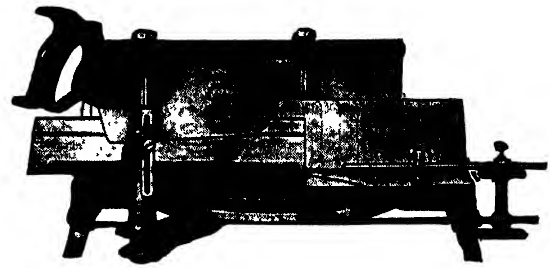


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FIG. 9.2. Mitre Box.

used for hollows and for grooving and edge shaping. Veining or carving tools are gouges of vee or circular shape, and are employed in ornamental carving.

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FIG. 9-3. Wood Chisel.

The **Sloyd knife,** Fig. 9-5, is commonly used in wood-carving, and for marking and layout work where pencil lines are not sufficiently accurate.

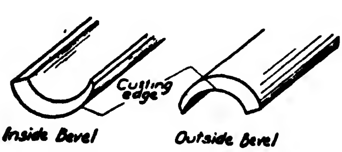

FIG. 9-4. Gouges.

FIG. 9-5. Sloyd Knife.

113. A hand plane is essentially a chisel carried in a frame. The **jack plane,** illustrated in Fig. 9-6, is so named because it may be used to do the work of several other planes. The plane iron cap is clamped to the plane iron or cutter, and breaks the shavings as they enter the throat of the plane. The lever cap locks the plane iron to the body of the plane. The cutter is advanced or retracted for a coarse or fine cut by the adjusting nut.

The jack plane is about 14" long; the smoothing plane, fore plane and jointer planes are almost identical with the jack plane except that they are

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FIG. 9-6. Jack Plane.

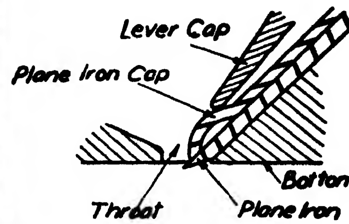

FIG. 9-7. Jack Plane Cutting Principles.

respectively 8", 18" and 30" long. The **block plane** is a small plane for planing end grain. It has no cap iron or handle. The plane iron in a block plane is set at a smaller angle to the plane bottom than the jack plane iron and its bevel is turned up instead of down as in Fig. 9-7.

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FIG. 9-8. Rabbetting Plane.

Fig. 9-8 illustrates a **plane for cutting rabbets.** It has a wide cutter which is set at an angle to the side of the plane as well as to the bottom, so that it will operate more easily on cross-grain work. It is equipped with a depth gage, and with an adjustable fence or guide, as illustrated, which determines the width of the rabbet.

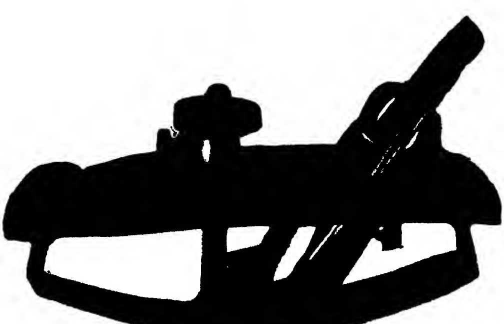

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FIG. 9-9. Circular Plane.

Combination planes are somewhat similar to rabbetting planes but employ specially-shaped cutters for cutting dadoes, beading and moldings. Planes are available with as many as one hundred stock cutters of

various shapes. **Circular planes,** illustrated in Fig. 9-9, **have flexible steel** bottoms that can be adjusted by the vertical screw and nut shown to plane convex and concave surfaces.

114. Drills and bits are used for boring holes in wood. Fig. 9-10 illustrates an **auger bit** which is usually obtained in sizes ranging from ¼" to 1" by sixteenths. The head of the bit consists of the screw, lips, and spurs. The screw serves to pull the bit into the wood; the spurs outline the hole and cut off the fibers which are then picked up by the lips and removed by the helical twist. The auger bit permits accurate hole boring, but its effective life is limited by the metal that can be removed from the spurs and lips in resharpening.

The **taper head or twist drill** is extensively employed in wood boring because the greater part of the fluted portion of the drill can be ground away in resharpening. It requires pressure to make it cut, does not elevate the chips as readily as the double-twist auger bit, and is therefore not as satisfactory for deep hole boring. It is very satisfactory for end grain service, and is extensively used for cross-grain where absolutely smooth holes are not required.

Solid center single twist auger bits have a cylindrical body of comparatively small diameter about which a single helicoidal twist is formed. They have heads similar to the bit shown in Fig. 9-10, and serve the same purpose. The solid center bit is somewhat more resistant to drilling torque than the double-twist bit. A **ship auger** has a single outside twist with no center section. The chips travel through the center of the bit, and it is used for deep-hole drilling. There are numerous other varieties of bits each adapted to particular operations. Requirements of the automobile body industry, for instance, have resulted in the development of boring machines with power feed which cannot feasibly employ auger bits with screw points. The **brad-point machine bit** illustrated in Fig. 9-10 is very popular for this class of work. It has a point which steadies the tool while boring but does not pull the bit into the wood. When a straight hole is bored in a surface perpendicular to the bit axis, a short small brad is preferred because it requires a minimum of power. When a hole at an angle to the surface is to be bored, however, the brad must be long enough to extend beyond the spurs.

There are many types of shanks used on boring tools for wood. The **square** auger bit shank is employed for hand-operated bits and drills. For machine operation, cylindrical or **straight-shank** drills and bits are often employed. **Taper-shank** drills are quite commonly used in drilling machines. The **Morse Taper** series is employed for drill shanks and also for wood-working and metal-turning lathe center shanks. **The Brown and Sharpe Taper series** is employed for other metal-

working machinery. Shank sizes in either of these series are designated by numbers. The dimensions of tapers in these series as well as other series, such as the Jarno taper, may be found in handbooks or trade catalogs.

Fig. 9-11 illustrates a multi-toothed cutter for shaping the top of a hole to receive a flat head wood screw. An **expansive bit** is a special auger bit with an adjustable cutter which makes it possible to bore holes from 1″ to 4″ in diameter. The bit is furnished with a gage for setting the cutters to various diameters. Fig. 9-12 illustrates a **hole saw** or

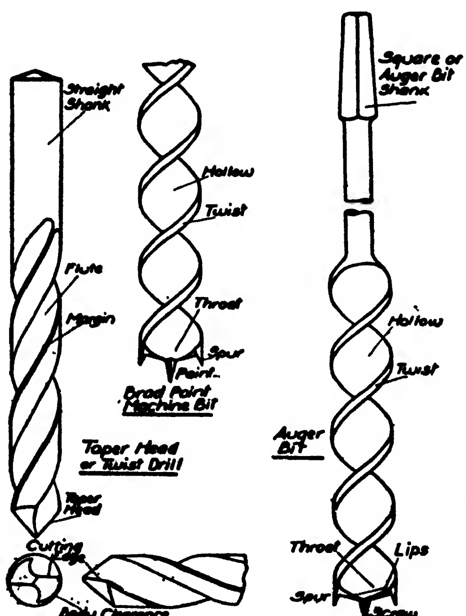

FIG. 9-10. Wood Boring Tools.

FIG. 9-11. Rose Countersink.

Black & Decker Mfg. Co.

FIG. 9-12. Hole Saw.

trepanning tool. **Trepanning** involves boring a hole by removing an annular rim of material, instead of reducing to chip form the entire volume of the material originally in the hole. The drill in the center serves to pilot the hole saw. This cutter is employed on metal and other materials as well as on wood. The **scratch awl** is used for layout and marking and may be employed to provide anchor holes for wood screws.

Fig. 9-13 shows a ratchet type **bit brace** for holding auger bits and straight-shank drills. The shank of the drill or bit fits into the chuck at the right, and is clamped by rotating the outer shell by hand. The ratchet can be set to operate in either direction or not at all. The **hand drill**, Fig. 9-14, has a three-jaw chuck for straight-shank tools, which is closed

by hand. The hand drill is generally employed for smaller sizes of holes. The **breast drill** resembles the hand drill, but has a curved plate at the top (against which the operator may press with his body) instead of the long handle.

115. Woodworking machinery is extensively used in modern practice. Fig. 9-15 illustrates a **circular saw table.** The ripping fence can be set at various distances from the

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FIG. 9-13. Bit Brace.

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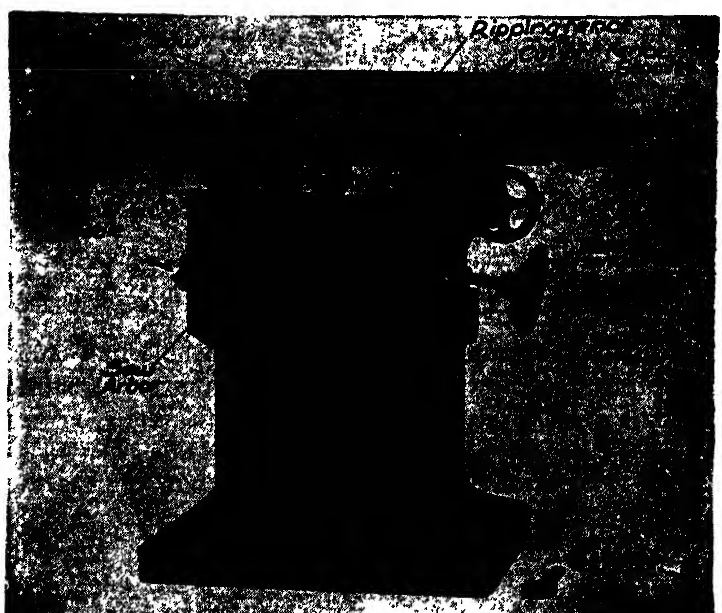
FIG. 9-14. Hand Drill.



Crescent Machine Co.

FIG. 9-15. Circular Saw Table.

saw, and is employed as a gage for cutting boards to definite widths. The cut-off fence is employed for end cutting where the long dimension of the board moves at right angles to the saw. The table handwheel is used to set the saw table at an angle other than 90° to the saw, and makes it possible to saw boards with one bevel and one square edge. The saw handwheel serves to adjust the height of the saw above the surface of the table. The cut-off fence may be used on either side of the saw, and can be set around at an angle so that bevels as well as square ends may be cut.

Saws with either cross-cut or ripping teeth, essentially similar to those illustrated in Fig. 9-1, are employed for circular saws. Grooves for notched joints may be cut by using a series of saws properly spaced by collars or washers. **Dado heads,** for dado, plough, and rabbet cutting, may be

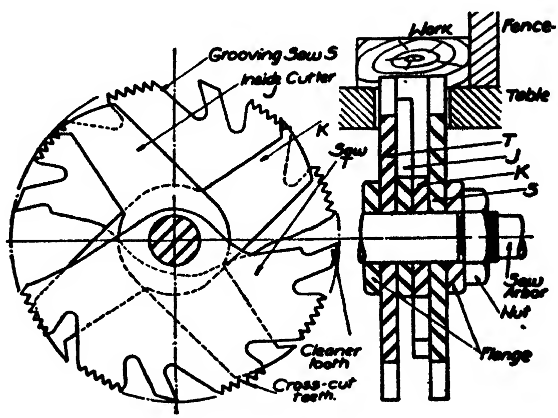
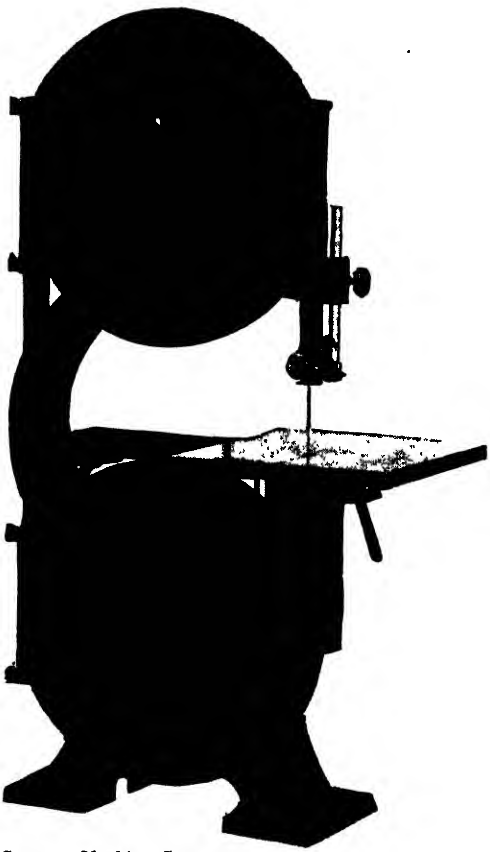


Fig. 9-16. Dado Head.

used on saw tables. The head shown in Fig. 9-16 has two grooving saws S and T, which have cross-cut teeth and four chisel shaped *cleaner* teeth on each blade. (The *cleaner* tooth insures a sharp, square corner; the cross-cut teeth have a small set so that they do not project beyond the sides of the cleaner teeth.) The two inside cutters have only two teeth each, which allow a great deal of space for chips, but they cannot be used for smooth cutting without employing the outside cutters. (In Fig. 9-16 the work is viewed from the rear, and the left edge of the work is against the fence.)

A **bandsaw** for general purpose work is illustrated in Fig. 9-17. The saw is a continuous steel ribbon with teeth along one edge, which runs over a pair of wheels whose diameters denote the size of the saw. The work is placed on the table and fed by hand against the front edge of the saw. The thrust of the work is borne by roller guides which are set as close



Crescent Machine Co.

FIG. 9-17. Band Saw.

as possible to the work. Band saws are obtainable in widths from ⅛" up, and are generally made with a brazed lap joint. Band saws with tilting tables, and saws in which the frame tilts, thereby permitting angular or beveled cuts, are available. The band saw is used for cutting lumber to shape, and for curved work where its narrow blade permits small radii to be sawed.

Scroll saws or **jig saws** are used for cutting internal and external irregular curves, as illustrated in Fig. 9-18. The saw blade has a reciprocating motion, and cuts on the down stroke. The scroll saw can be used for irregular holes in work where a starting cut from the outer edge to the hole, which is required in band-sawing, is not desirable. In this type of work a hole is drilled through the piece, and the saw is passed through the hole and then clamped by the upper and lower chucks.

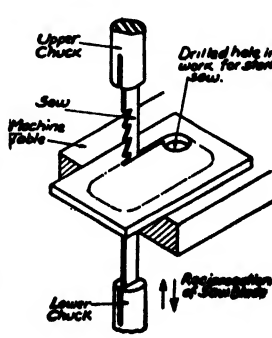


FIG. 9-18. Scroll Saw Principles.

116. The **wood planer** is employed for surfacing rough lumber and planing wide boards. The cutter head is composed of a cylindrical body with two, three, four, or six knives which are clamped to the body but may be adjusted to compensate for resharpening. The **wood jointer** is used for preparing edges to be joined accurately. The table is adjustable for various depths of cut. The fence *F* is adjustable for finishing bevels as well as squared stock.

The **wood shaper** is employed for moldings and similar work. It has a vertical rotating

spindle, on which cutters or knives of different shapes may be placed and clamped. In general, two types of cutters are used as illustrated in Fig. 9-21. The shaper cutter *C* may be obtained in a great variety of molding shapes, but if such cutters are not available for a particular application, the shaper head with hand ground blades *B* is substituted. Shapers can be used for curved work by removing the fences *F* and holding and turning the work by hand.

117. Fig. 9-22 shows a bench-type **drill press** which may be used for both wood and metal drilling. The spindle rotates in a non-rotating

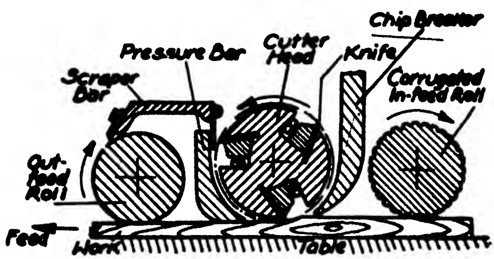


Fig. 9-19. Wood Planer Principles.

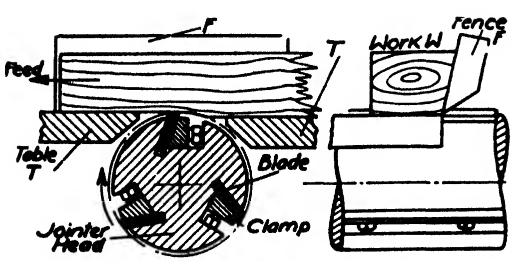


Fig. 9-20. Wood Jointer Principles.

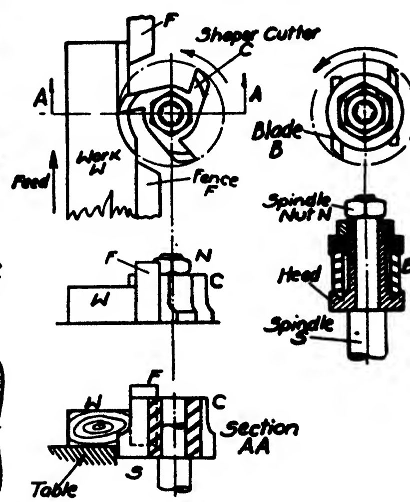


Fig. 9-21. Wood Shaper Principles.

sleeve or quill *S*. The sleeve may be moved axially for feeding the drill by turning the pinion which engages the rack teeth in the sleeve. The spindle is driven by a driving flange through which the spindle end may slide. The driving flange is bolted to the two-step spindle pulley which is driven by a V belt from a pulley on the motor (not shown). The motor is bolted to the seat with the motor shaft in a vertical position. The entire head is adjustable vertically. The drill shown has two speeds only, but five- and six-speed drills are commercially available. The table is carried by the knee which is adjustable vertically and horizontally. The table may be hand-rotated and clamped at any point. The entire knee may be swung out of the way so that work may be placed on the base.

A **three-jaw drill chuck** of the latest design is shown in Fig. 9-23. Rotating the outer sleeve by hand or by a key fitted to the sleeve gear teeth

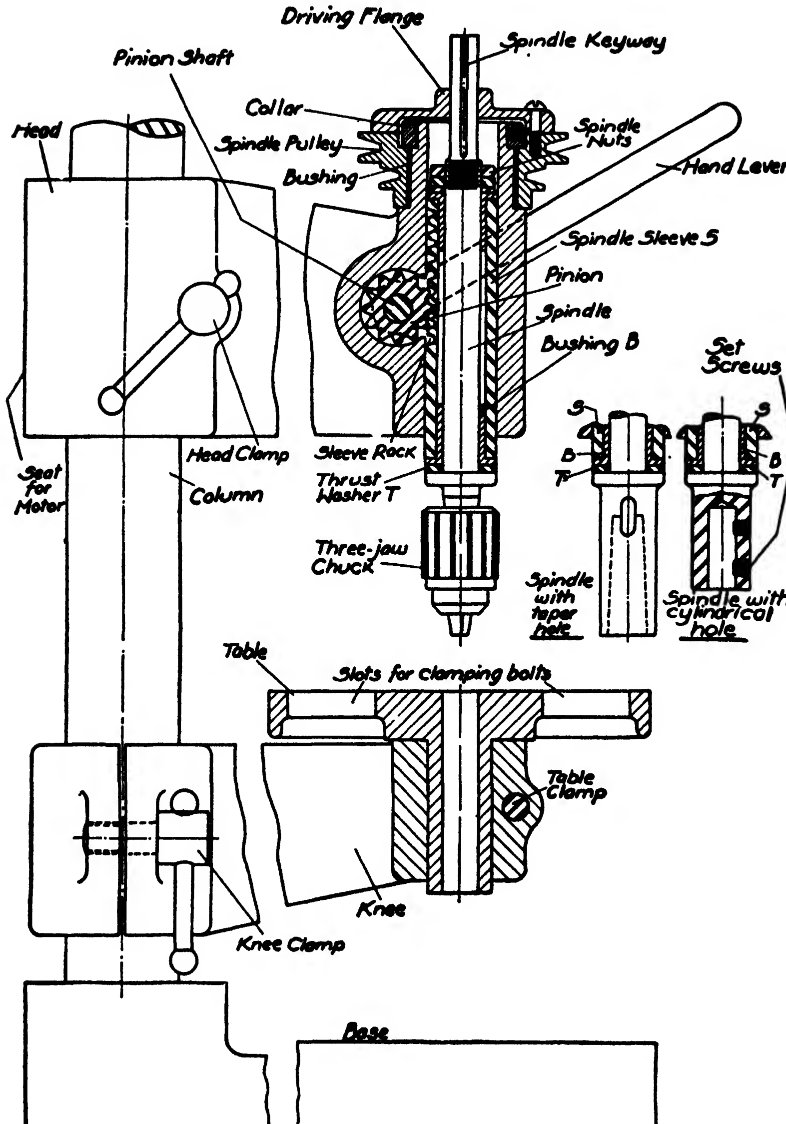
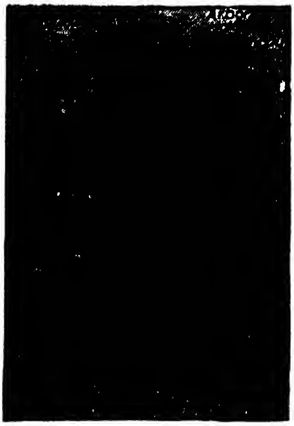


FIG. 9-22. Drill Press.

opens and closes the three self-centering jaws. The arbor hole in the drill chuck fits the tapered end of the drill press spindle. Fig. 9-22 also shows

a spindle end with a **Morse Taper hole** for taper-shank drills, and a spindle end with a **cylindrical hole** for router bits and other wood-



Jacobs Mfg. Co.

FIG. 9-23. 3-Jaw Ball Bearing Drill Chuck.

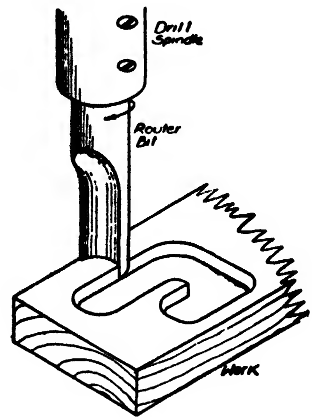


FIG. 9-24. Routing Principles.

cutting tools. The chuck and taper hole spindle ends are used in both metal and woodworking drill presses; the cylindrical-hole spindle is employed almost exclusively for woodworking machines. Fig. 9-24 shows the principle of **wood-routing** or irregular blind-groove cutting; the work is moved manually on the drill press table while the end of the router bit cuts out the desired groove; the drill spindle is generally fixed in a definite vertical position so that the groove will be of the same depth.

Fig. 9-25 shows a **mortising tool,** which consists of a holder for a hollow chisel, attached to the drill press sleeve, and a mortising bit (without a point) rotating within the chisel. As the bit bores the hole, the chips are carried up in its flutes and emerge from the chip holes in the chisel. The sharp edges and corners of the chisel sink into the wood as the boring proceeds, and square up the mortise. If a rectangular mortise with a length equal to twice its width is required, the square mortise operation is performed twice. **Gang**

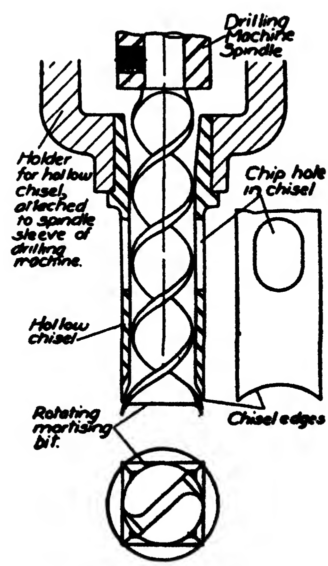
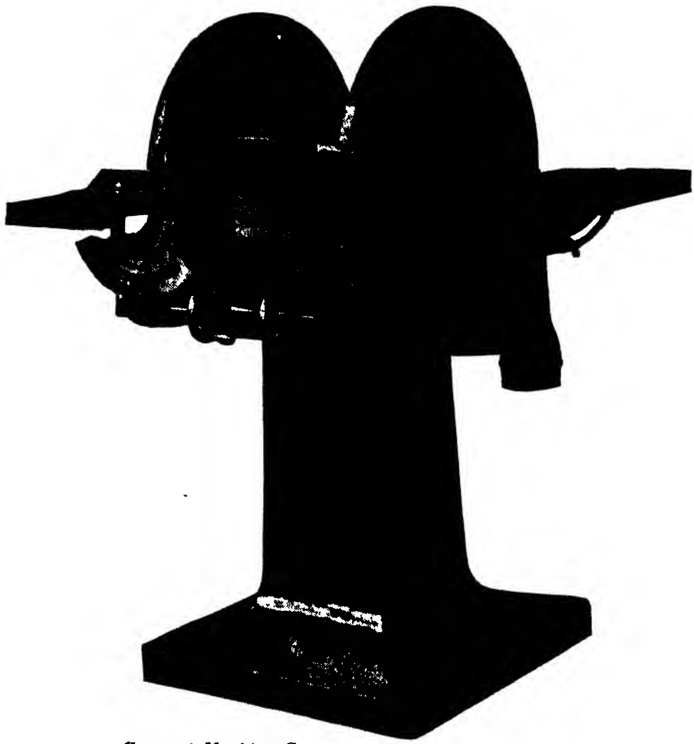


FIG. 9-25. Hollow Chisel for Square Mortises.

mortising tools are also available for long rectangular mortises, cutting the entire mortise in one operation.



Crescent Machine Co.

FIG. 9-26. Disc Grinder.

118. Fig. 9-26 illustrates a **disc grinder** which consists of a pair of wheels on which abrasive discs are glued. The tables are adjustable to various angles. Fig. 9-27 illustrates the principle of operation of a **belt sander** which has an abrasive paper or cloth belt. Both these machines are used for finishing operations in wood-working, and are far superior to hand sand-papering in economy of time and labor.

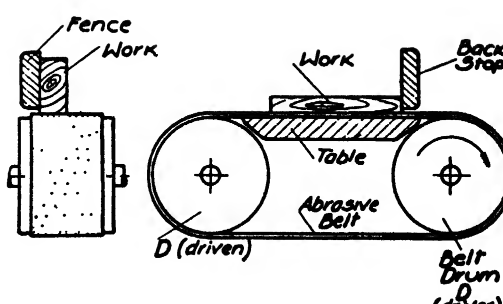


FIG. 9-27. Belt Sander Principles.

Many **other machines for woodworking** are in common use. The molder is used for cutting moldings, hexagons, full- and semi-rounds, and other strips of irregular cross-section. It resembles a combination of planer and jointer with two additional vertical cutter-heads. The matcher is a machine with six cutter-heads for simultaneously finishing all sides of matched flooring stock. The tenoner is a machine with several cutter-heads for machining in one operation tenons of varied shapes.

119. A **lathe** is essentially a machine tool for producing and finishing surfaces of revolution. The machine is designed to hold and revolve work about an axis of rotation so that it may be subjected to the

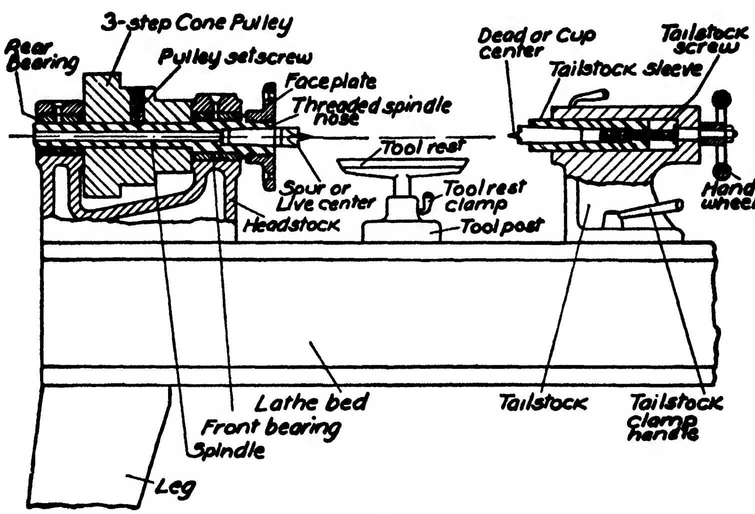


Fig. 9-28. Wood Turning Lathe.

action of a cutting tool moving in a horizontal plane through the axis of the work. When the cutting tool moves in a longitudinal direction or parallel to the axis, the operation is known as **turning**; when it moves in a transverse direction, it is known as **facing.** In hand lathes for wood-work and some metal work, the cutting tool is guided by hand; in engine lathes the cutting tools are generally guided by the machine tool itself.

Fig. 9-28 shows the front view of a **wood-turning lathe.** The rotating **spindle** carries a **live or spur center** on which the piece to be turned is placed. The other end of the work is supported by and rotates on the non-rotating **dead or cup center.**

Many modern lathes have a motor built into the headstock with the spindle serving as the motor shaft. The lathe shown, however, is belt

driven and has a three-step cone pulley which is driven from a countershaft cone pulley. The spur center fits in a tapered hole in the spindle which is hollow, so that the center may be removed by inserting a rod from the rear. The **headstock** is fastened to the lathe bed and carries the bearings in which the spindle rotates.

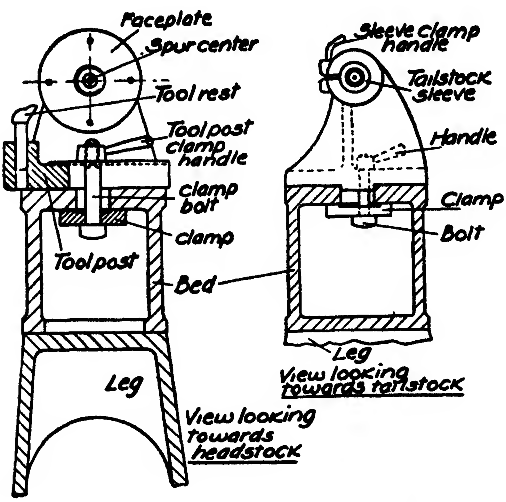


FIG. 9-29. Wood Turning Lathe.

The **tailstock** may be moved anywhere along the **lathe bed** and can be clamped in place at any point. The tailstock is keyed to the bed, however, so that the headstock and tailstock centers will always be in alignment. The tailstock carries a non-rotating sleeve keyed to the tailstock, which may be advanced or retracted by means of the tailstock sleeve screw operated by the handwheel.

The dead center fits in a Morse Taper hole in the sleeve and may be removed by retracting the sleeve, thereby bringing the end of the tailstock screw against the rear of center and forcing it out. Major adjustment for work length is made by moving the tailstock and clamping it in position; subsequent fine adjustment to provide the proper bearing for the work is made by turning the handwheel. The sleeve clamp handle is used to clamp the sleeve after the center is adjusted to the work.

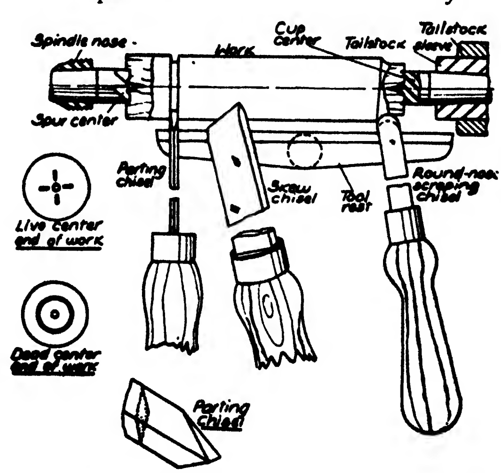


FIG. 9-30. Wood Turning Tools and Operations.

The **tool post** may be placed anywhere on the lathe bed and clamped in position; the **tool rest** is then adjusted for height and set either parallel to the work axis or in an angular position, and clamped by the tool rest clamp.

120. Fig. 9-30 shows various turning operations. The **stock,** which is generally roughly cylindrical, is centered and driven on the live center with a mallet. The dead center is brought up to approximate position by moving up the tailstock and clamping it. The tailstock sleeve is then adjusted and clamped so that the dead center is imbedded in the work as indicated (a small quantity of mineral oil having been previously applied to the center). The tool post is placed in position and clamped, and the tool rest is brought to the proper height and clamped.

The **spurs** on the live center cause the work to rotate. Cutting should be performed by moving the tool *towards* the headstock so that the bearing will take the cutting thrust. An **outside bevel gouge** is generally used for converting the stock from its rough original shape to a cylindrical form. The **skew or shaving** chisel is used to obtain a

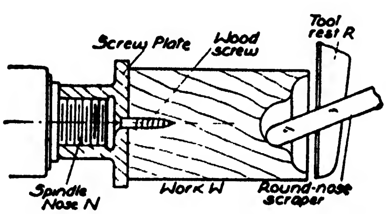


FIG. 9-31. End Facing.

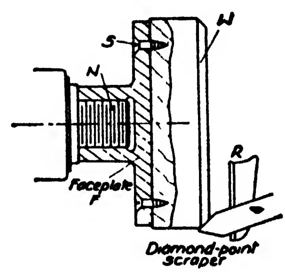


FIG. 9-32. Facing Operations.

smooth finish after roughing with the gouge. **Scraping chisels** do not give as smooth a finish as the skew chisel but are employed for both finishing cuts and for grooving and angular cuts. The **cut-off or parting chisel** is generally used for grooving work at various points to definite diameters to serve as a guide in turning, thus eliminating frequent measurement. Turning chisels are equipped with wooden handles. The handle is held in the left hand, and the right hand guides the cutting edge. The parting chisel, however, is held in the right hand while a caliper to check the groove diameter is held in the left hand.

The lathe spindle has a threaded nose so that a **faceplate,** shown in Fig. 9-32, may be attached. The faceplate is employed for facing operations, for work which cannot be conveniently turned between centers, or for end-cutting operations. Fig. 9-32 shows a chamfering operation in which the method of attaching the work to the faceplate is shown. If screw holes in the work are undesirable, a backing piece shown in Fig. 9-33 may be used. The work is glued to the backing piece with a piece of paper between

the two so that the parts may be easily separated after turning or facing is performed. Fig. 9-31 shows a single-screw faceplate which is used for facing and for end turning operations on small work. In making the part

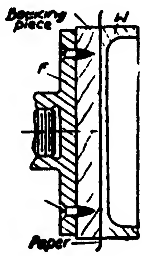


FIG. 9-33 Facing Operations.

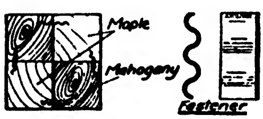


FIG. 9-34. Fastening Sectional Stock.

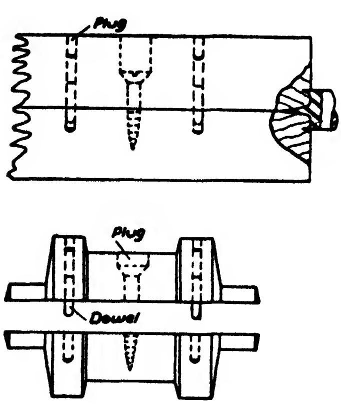


FIG. 9-35. Two-piece Pattern Turning.

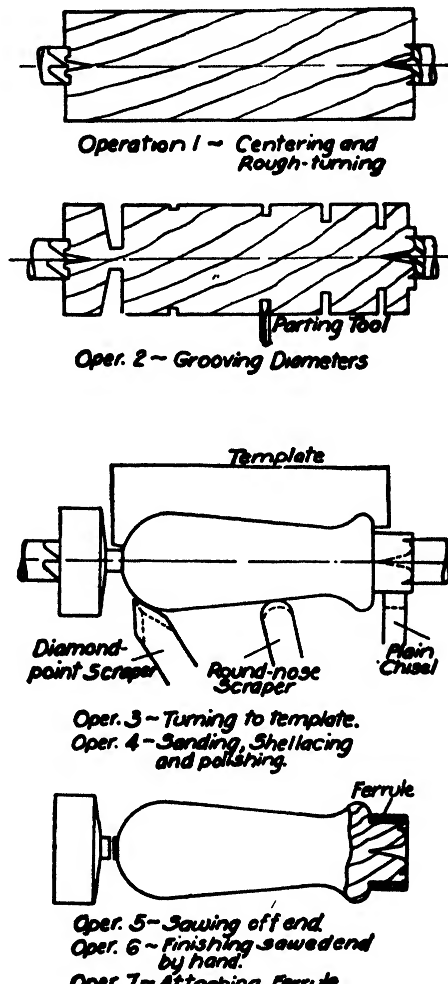


FIG. 9-36. Making a Wooden Handle on the Wood-turning Lathe.

shown, the outer periphery is first turned by holding and driving the work as shown with the dead center supporting the free end. The dead center is then removed and the end-cutting operation is performed.

Fig. 9-35 shows how **two-piece patterns** may be turned. The two halves are first dowelled and then locked together by a screw, and the centers located exactly at the parting line of the pattern. After turning, the screw is removed and the hole plugged with a wooden plug or with plastic wood.

Fig. 9-34 illustrates a method of building up stock for **ornamental wood turning** when a cylinder of alternate sections of maple and mahogany is required. The pieces are cut and planed smooth, glued together, and fastened by driving corrugated fasteners into the ends. After turning, the end sections containing the corrugated fasteners are cut off.

CHAPTER 10

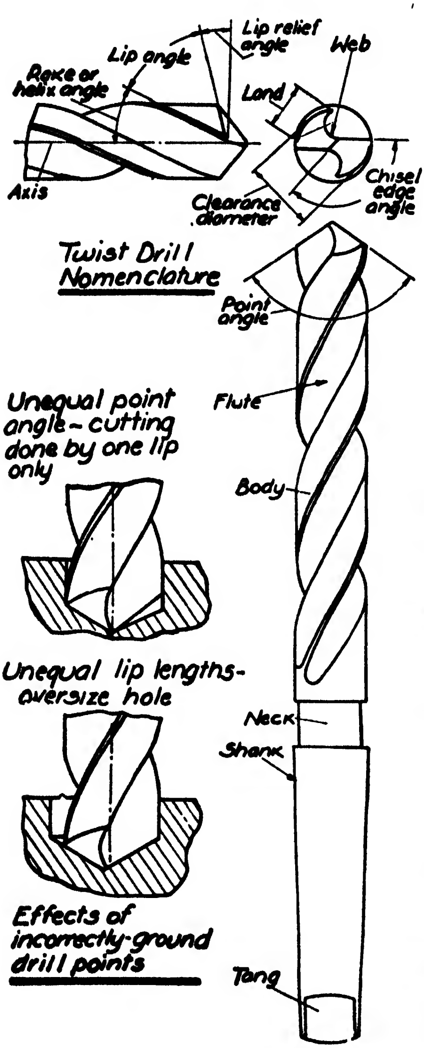
DRILLING AND ALLIED PROCESSES

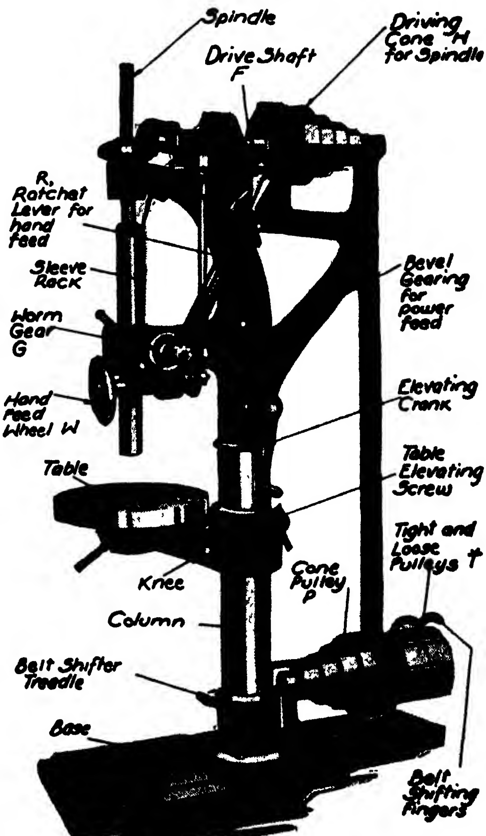
121. Drilling is one of several methods of originating **holes in** metal. Fig. 10-1 shows **a twist drill** which is the most widely used tool for cylindrical holes. In drilling a hole, the **point** of the drill is forced into the work, crushing the material immediately beneath the **web,** and thereby allowing the **two lips** or cutting edges to cut. A two-lipped twist drill will originate a true cylindrical hole if both lips are of the same length and at the same angle with the axis of the drill, and if the axis of the drill and its axis of rotation are coincident.

The **point angle** of a twist drill is generally 118° for drilling cast iron or steel; the **lip relief angle** is from 12° to 15°, and the **chisel edge angle** from 120° to 135°. The helical **flutes** provide rake for the cutting lips so as to curl the chips; they furnish a path for the escape of the chips and serve as channels for lubricants or coolants to reach the point of the drill. The drill is guided primarily by the two lips but also by the **margin** or full diameter edge. That portion of the drill immediately behind the margin is reduced in diameter to minimize the friction between the drill and the walls of the hole. The web is the central section that connects the two outer helical portions of the drill. The web thickness increases toward the shank, and thereby gives additional torsional rigidity to the drill.

122. There are three general types of **drilling machines.** The **bench drill press,** Fig. 9-22, which is described in Chapter 9, the **upright drill press,** Fig. 10-2, and the **radial drill press,** Fig. 10-3. In all three types, the spindle rotates in a sleeve which does not rotate but is free to move axially to provide the necessary feed for the drill. In the bench drill of Fig. 9-22, both the table knee and the head carrying the spindle are adjustable for various classes of work. In the drill press illustrated in Fig. 10-2, the spindle sleeve supports are fixed, and all adjustment for different classes of work is made by moving the table, which is accomplished by turning the elevating crank. The table can be moved in a horizontal plane, clamped at any point, or if desired, swung out of the way so that large work may be placed on the base. The machine is equipped with a ratchet lever R for hand feeding the drill. The hand wheel W is fastened to a worm shaft whose worm engages a worm gear G on the pinion feed shaft. This feeding motion is much finer than that obtained by using the lever R.

The drill press illustrated in Fig. 10-2 is driven from a countershaft by a flat belt to the tight and loose pulleys T. The machine can be started or stopped by stepping on the belt shifter treadle, which causes the belt shifting fingers to move the belt from the loose to the tight pulley and vice-versa. The cone pulley P drives the pulley H which is fastened to the drive shaft F, and which in turn drives the spindle by bevel gearing. By shifting the belt



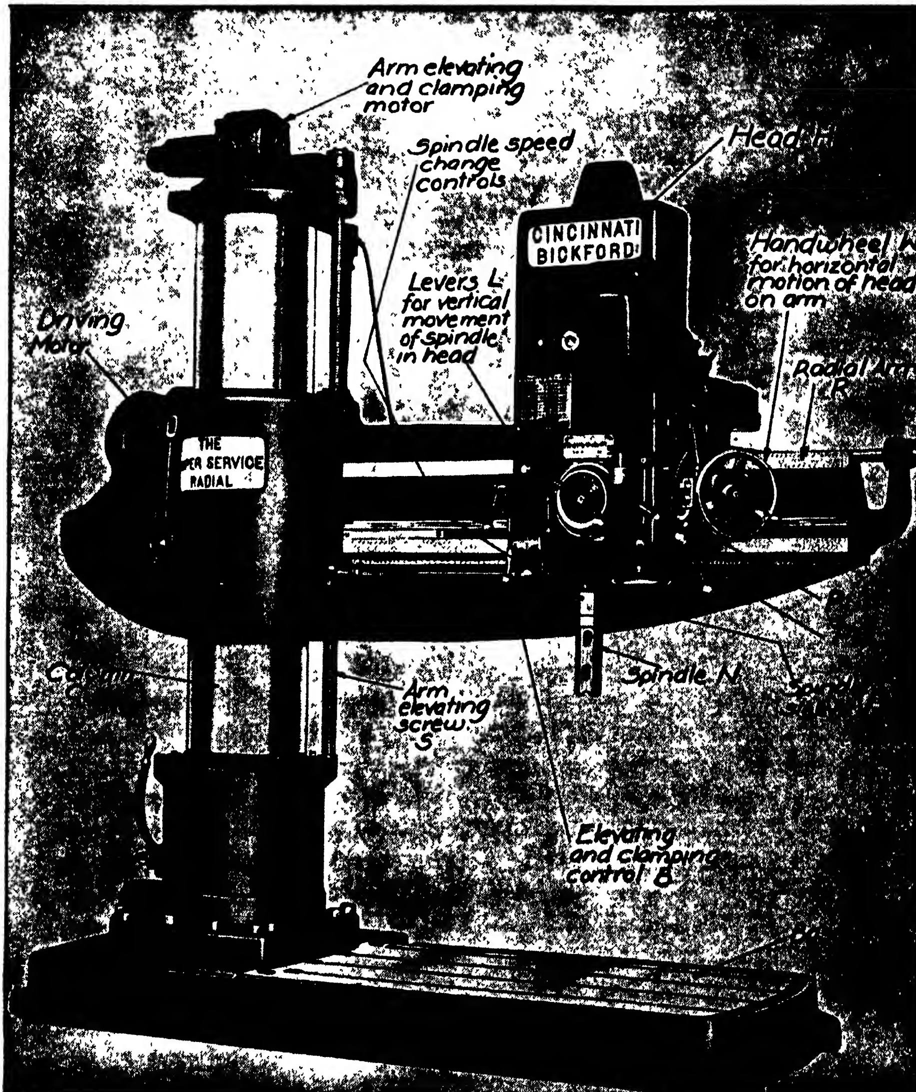


Buffalo Forge Co.

FIG. 10-1. Twist Drill Nomenclature. FIG. 10-2. Upright Power Drill Press.

to different steps on the cone, four direct spindle speed changes are available in the drill shown. In some machines four additional speeds may be obtained by using back gearing. The machine is equipped with a power

feed; the worm is driven by bevel gearing through the vertical shaft which is driven by change gearing from F. Three power feeds, approximately



Cincinnati Bickford Tool Company

Fig. 10-3. Radial Drill.

.005", .007" and .011" per revolution of the spindle, are available in the machine shown.

The **radial drill** of Fig. 10-3 has a column C which may be rotated about the base. On the column is the radial arm R which moves in a horizontal plane with C, but may also be moved in a vertical plane. The head H carries the spindle N, and may be moved radially along the arm. The radial drill is therefore adapted to heavy work where it is easier to move the drill than the work, as illustrated in Fig. 10-4. Spindle speed and feed changes are effected by gearing; there are 18 feeds available, varying from .006″ to .125″ per revolution of the spindle, including leads for tapping 8, 11½, and 14 pitch pipe threads. Spindle speeds range from 14 r.p.m. to 1,500 r.p.m. In Fig. 10-3, the driving motor provides power for the spindle speeds and feeds and provides a rapid traverse for the head H. The radial arm is elevated or lowered and clamped in position on the column by the motor at the top of the column. The elevating and clamping controls are located at T.

A **sensitive drill** is a vertical or upright machine of comparatively light construction adapted to very high speeds, and used for delicate work.

123. Drill press spindles generally have a Morse taper hole in the spindle as illustrated in Fig. 9-22. Twist drills with taper shanks may be fitted directly to the tapered spindle hole, but in many cases the taper shank of the drill is smaller than the spindle socket. In such an instance, a **collet** or sleeve illustrated in Fig. 10-5, is employed. The collet may be removed by driving with the **drift,** Fig. 10-6. The drill itself is removed from the collet in the same manner. The taper shank drill is held primarily by the friction between the shank and the socket, although the tang provides some additional resistance to torque.

Straight-shank twist drills which have a cylindrical shank of the same diameter as the drill itself are generally held either in **three-jaw chucks** of the type illustrated in Fig. 9-23, or in **two-jaw chucks** shown in Fig. 10-8. Both types of chucks are generally held by inserting the arbor illustrated in Fig. 10-7 in a tapered hole in the body of the chuck. The arbor in turn is held by inserting its tapered shank in the spindle socket. Fig. 10-10 illustrates a **single-purpose drill chuck,** extensively used for mass production where tool sizes are rarely changed. It has a split body with a hole to fit the drill shank which is clamped in place by the taper-threaded nut. It can be employed to drive drills, taps, reamers, and straight-shank milling machine cutters. Fig. 10-11 illustrates another single-purpose drill chuck, the so-called **bayonet chuck,** which is employed on automatic drilling machinery. Single-purpose chucks are less expensive than the adjustable variety, will permit smaller center distances on multiple hole drilling, and can be easily removed and replaced.

124. For wood drilling, the work can ordinarily be held by hand. Except where small holes are drilled in comparatively large or heavy parts,

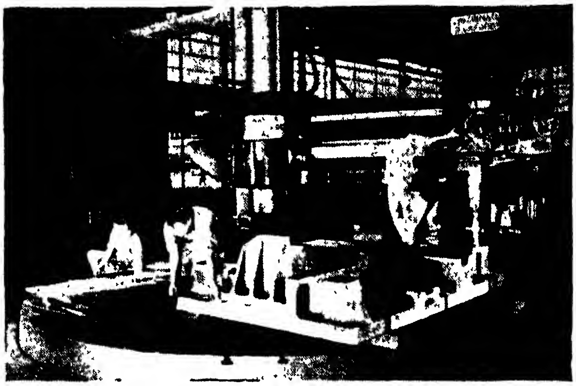


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FIG. 10-4. Radial Drill with 8 Foot Arm Employed in the Tool Room of the Ford Motor Co.

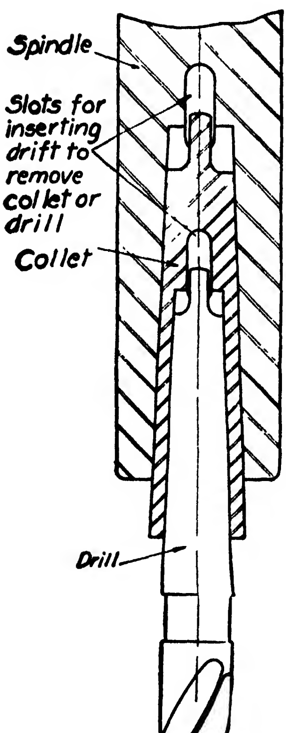


FIG. 10-5. Application of Collet or Sleeve.

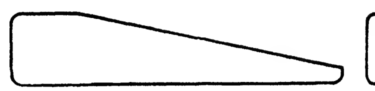


FIG. 10-6. Drift or Key for Removing Drill or Collet from Socket.

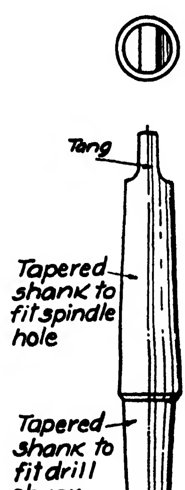
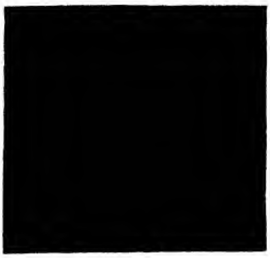


FIG. 10-7. Arbor for Three-Jaw Chuck.

however, metal drilling requires so much torque that the work should be held in a vise or be clamped to the drill press table.



The Standard Tool Co.

FIG. 10.8. Two-jaw Drill Chuck.

The Standard Tool Co.

FIG. 10-9. Screw, Jaws and Wrencn for Two-jaw Drill Chuck.

Fig. 10-12 shows a small vise designed for use on a drill press. In drilling small holes, the vise may be held by hand; for larger holes, two clamps and tee-bolts illustrated in Fig. 10-13 are provided. The vise can be used in the position shown in Fig. 10-12, or it can be laid on either side since these sides have finished surfaces perpendicular to the base. Extra slip jaws to permit holding cylindrical or hexagonal bars are also provided. Fig. 10-14 shows a milling machine vise which may be used on a drill press. The screw of the vise rotates in a fixed nut in the movable jaw. The tee-bolt slots permit the base to be clamped to the drill press table. This vise may also be mounted on a swivel base which is graduated so that the vise jaws may be set at any convenient angular relation to the table.

Jacobs Mfg. Co.

FIG. 10-10. Single-purpose Drill Chuck.

Vee-blocks are accurately made cast iron or steel blocks and are used to hold cylindrical work, as illustrated in Fig. 10-15 and 10-16. Fig. 10-15 shows the arrangement for drilling a radial hole in a cylindrical part. In order to insure the coincidence of the hole and part

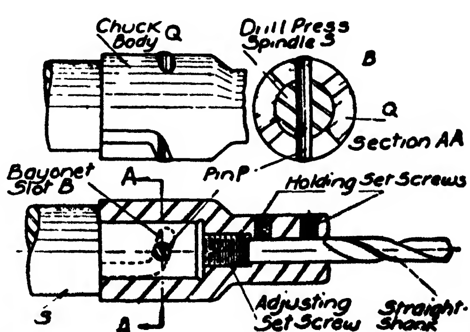
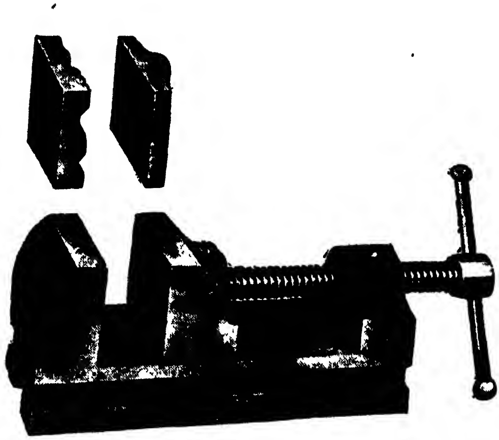


FIG. 10-11. Bayonet Chuck for Automatic Drilling Machinery.



Stanley Tools

FIG. 10-12. Drill Press Vise.

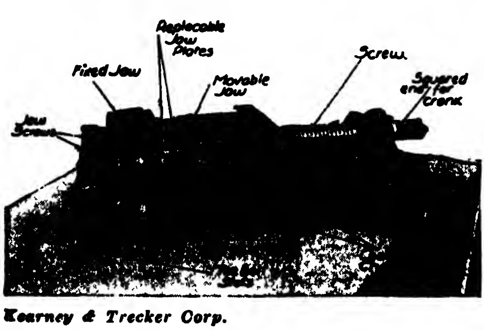
axes, a line is drawn on the surface of the work with a scriber and scale, using the keyseat rule blocks illustrated in Fig. 10-18 to insure parallelism of the line and the part axis. The work is then placed in a vee-block, with the scribed line on top as shown in Fig. 10-17; a square is placed against the side of the part and a scale is used to determine the distance from the square edge to the line. If this distance is equal to the radius of the cylindrical part, the part is properly located. The arrangement shown in Fig. 10-16 is usually employed when center holes for turning operations are required; if the part to be drilled is very long, it may be clamped to the vee-block at its middle or even at its upper end, and the projecting portion of the bar allowed to extend through the central hole in the drill press table.

Stanley Tools

FIG. 10-13. Clamp and Tee-bolt for Fastening Drill Press Vise to Drilling Machine Table.

Work is also held in place by clamps and bolts. Two types of clamps are illustrated in Fig. 10-19; other types are shown in this and other chapters.

125. Two-lipped twist drills with either taper or straight shanks are satisfactory cutting tools for holes in cast iron and steel. **Straight-fluted drills** shown in Fig. 10-22 are used for copper or brass; they manifest less tendency to "dig in" than the helically-fluted tool. For heavy feeds and comparatively deep holes, **oil-hole drills** illustrated in Fig. 10-23 are employed. These drills have holes drilled from the solid metal through the body of the



Kearney & Trecker Corp.

FIG. 10-14. Plain Milling Machine Vise.

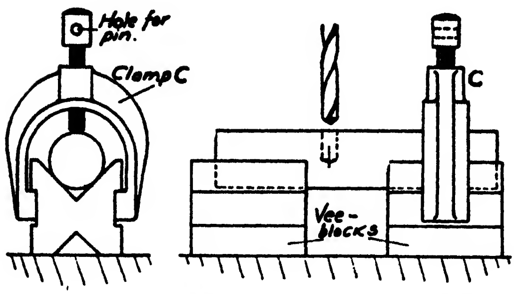


FIG. 10-15. Using Two Vee-blocks and a Clamp for Drilling Cylindrical Parts.

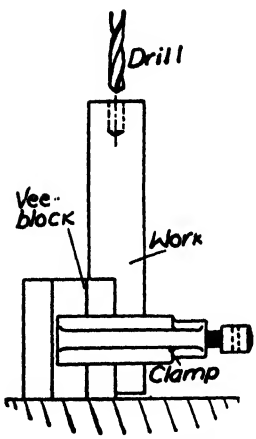


FIG. 10-16. Drilling a Hole in the End of a Cylindrical Part.

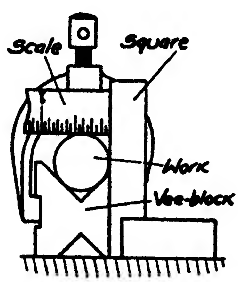


FIG. 10-17. Setting Work in a Vee-block.

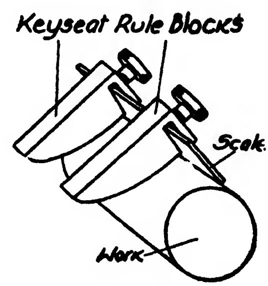


FIG. 10-18. Keyseat Rule Blocks and Scale.

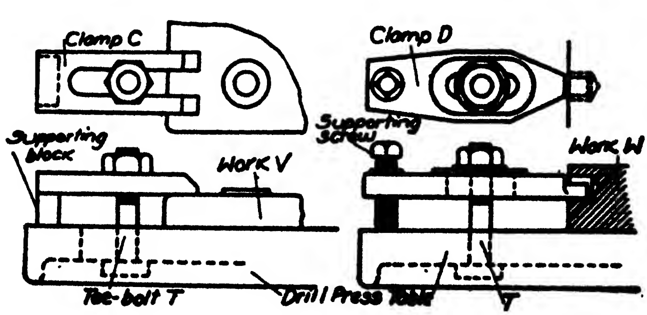


FIG. 10-19. Clamps.

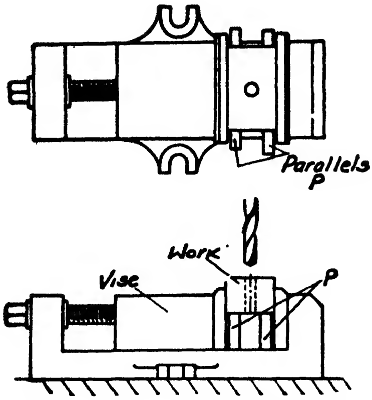


Fig. 10-20. Drilling Operation on Work Resting on Parallels in Plain Vise.

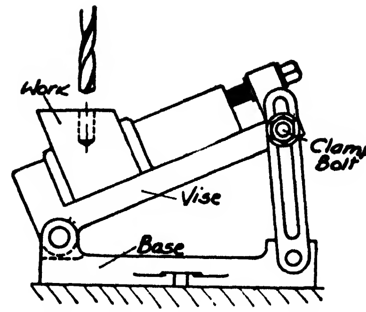


Fig. 10-21. Drilling Operation on Work with Angular Surface Held in Adjustable Angle Vise.

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Fig. 10-22. Straight-fluted Drill.

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Fig. 10-23. Straight-shank Oil-hole Drill.

MATERIAL BEING DRILLED	CUTTING SPEED FEET PER MIN.	COOLANT OR LUBRICANT
Cast and Alloy Steels	40	Soda Water, Kerosene or Turpentine
Alloy Steel Drop Forgings	50	"
Tool and Carbon Steel Drop Forgings	60	"
Hard Cast Iron	80	Dry
Malleable Iron	90	Soda Water
Mild Steel	120	Cutting Oil, or Soda Water
Medium Cast Iron	140	Dry
Brass and Bronze	300	Dry

Fig. 10-24. Cutting Speeds and Coolants for Drilling.

drill so that lubricants can be pressure-fed to the drill points. The lubricant not only assists in the cutting operation, but also facilitates the removal of the chips by forcing them out along the flutes of the drill. Oil-hole drills may be employed in drill presses but they are generally used in automatic machinery where the drill is stationary and the work rotates.

Taper shank twist drills are obtainable in diameters from ⅛″ to 3½″, the diameters varying by 1/64″ increments in the smaller, and by 1/16″ increments in the larger sizes. Straight-shank twist drills are obtainable in diameters from ⅛″ to 2″; in wire gage sizes from number 1 (.2280″) to number 80 (.0135″); and in letter sizes from *A* (.234″) to *Z* (.413″). Straight shank twist drills are obtainable in two lengths: the *standard* or long series, and the *jobbers'* or short series. (A ½″ standard drill is 7¾″ long; a ½″ jobbers' drill is 6″ long.) Taper and straight shank twist drills are available in both carbon and high-speed steel; the cost of the high-speed steel product is from two to three times the cost of the carbon steel drill. Fig. 10-24 shows representative **drilling practice** with **high-speed** steel drills. Carbon steel drills should employ the same lubricant but the speeds given in the table should be reduced 50%.

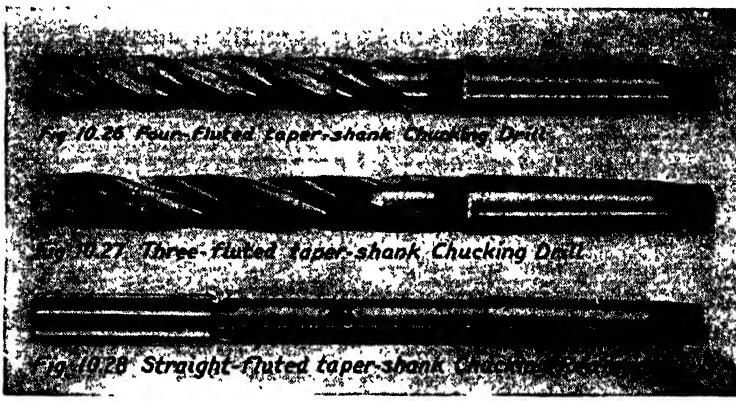
MAX. DIA. DRILL INCHES	FEED PER REV. INCHES
1/16	.002
1/8	.004
1/4	.006
1/2	.008
3/4	.010
1	.012
Over 1″	.015

Fig. 10-25. Drill Feeds.

Drill feeds are given in Fig. 10-25. Too great a feed per revolution may result in splitting the drill up the web; too small a feed may cause a burned drill end. Automatic drilling machines often employ a feed of from .001″ to .002″ per lip per revolution.

126. When a twist drill is used in a drill press for drilling comparatively deep holes, it will produce a cylindrical hole but the hole will not necessarily be straight, and its axis may not coincide with the drill spindle axis. When a drill is used in a lathe, however, the drill is stationary and the work rotates. If any misalignment is present, the drill tends to act as a boring tool, and will produce a hole whose axis is coincident with the axis of rotation but is larger in diameter at the bottom. In gun and rifle-barrel drilling, where special drilling machines are employed, a combination of these methods is sometimes used. The drill rotates at one-half its normal speed in one direction and the work rotates at the same speed in the opposite direction. The speed proportion may be varied but the combination of motion often produces holes with the best characteristics of the two original methods.

127. Two-lipped twist and straight fluted drills are satisfactory agents for originating holes, but if a cored hole is to be finished or if a drilled hole is to be enlarged, two lips do not provide sufficient support for the body of the drill and an irregular non-cylindrical hole will result. For this type of work, therefore, drills or reamers with three or more cutting edges must be employed.



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There are two general classes of reamers, **side-cutting** and **end-cutting** types. Figs. 10-26 and 10-27 illustrate drills for enlarging drilled holes or for machining punched or cored holes. Such reamers cannot be used for originating holes. Fig. 10-29 shows a **rose chucking reamer** which is used for the same purpose but has six cutting edges. These tools are of the end-cutting type. They have no radial clearance on

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FIG. 10-29. Straight-shank Rose Chucking Reamer.

the margin of the flute, but are provided with a back taper of about .002″ per foot. End-cutting tools can be resharpened frequently since all the cutting is done at the tips. Both chucking drills and rose reamers are made somewhat under the nominal size, as they tend to cut oversize. Holes are generally finished to exact size by using either hand or machine side-cutting reamers, with either straight or spiral flutes, illustrated in Figs. 10-28 and 10-30. **Hand reamers** are designed to remove only a few thou-

sandths of an inch of metal, and are very slightly tapered on the entering end to facilitate starting. The shank is .005″ under the body size so that the reamer may pass through the hole if necessary. The tang is square

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FIG. 10-30. Spiral-fluted Hand or Finishing Reamer.

so that the reamer can be turned with the wrench of Fig. 10-31. The **spiral-fluted reamer** has a series of separate edges cutting along a line in the hole, and will generally operate with less *chatter* than the straight

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FIG. 10-31. Tap and Reamer Wrench.

fluted reamer. The flutes are left-hand helices so as to avoid any *digging-in* action. Fluted chucking or machine reamers are similar to hand reamers but have cutting edges without any end taper. They are of course equipped

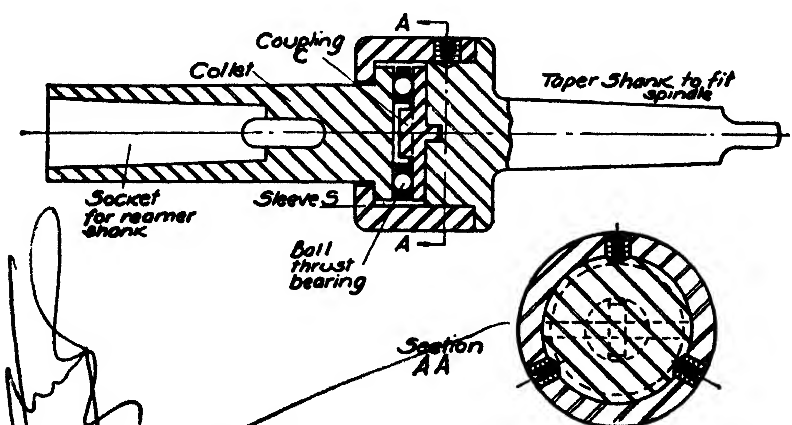

FIG. 10-32. Floating Holder for Reamers and Taps.

with either straight or tapered shanks for machine operation. Both side and end cutting machine reamers should be employed with some form of **floating holder** so that the reamer can align itself with the hole and cut to correct size. Fig. 10-32 shows a commercial holder in which the

collet is free to float sidewise, but must rotate with the shank because of the cross-keyed Oldhams' coupling. Fig. 10-33 shows another form of floating reamer and holder which is used in automatic drilling and reaming machinery.

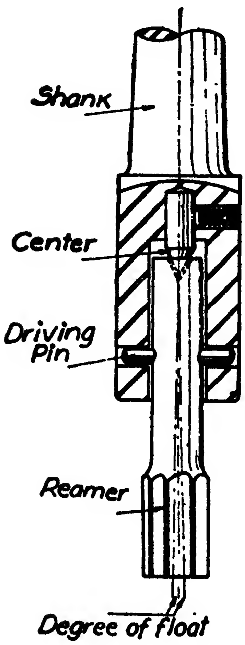

FIG. 10-33. Finishing Reamer in Floating Holder.

Fig. 10-34 shows an **adjustable reamer** with inserted blades. The main body of the reamer including the straight shank is a solid piece of steel. The blades are made of high-speed steel, and are held by a lock nut at one end and set screws at the other end. The blades can be moved axially along a tapered key which causes them to move radially outward at the same time. The reamer has an adjustment of 1/16", and the blades can be replaced by another set when they are worn to the limit of adjustment. The adjustable reamer permits variation in size, but its chief advantage is economy since the blades can be repeatedly adjusted and reground when they become dull.

Hand **expansion reamers,** Fig. 10-35, are used when it is necessary to increase diameters very slightly, especially in repair work. They are intended for light cuts only and are expanded by screwing in the taper expanding plug. The front pilot is generally .010", and the rear pilot .005", under the normal size of the reamer.

Fig. 10-36 illustrates a **shell reamer** and Fig. 10-37 the **arbor** or separate holder for this tool. Four-lipped drills, rose reamers, and fluted finishing reamers are available in shell types. Shell reamers are employed for large holes where the tool cost is high. Numerous sizes of shells are interchangeable with one arbor, thus making this type

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FIG. 10-34. Straight-shank Adjustable Chucking Reamer.

of tool convenient and economical for use in the small shop; it is also useful in production work since new shells are less expensive than a new solid reamer.

Fig. 10-38 shows a **core drill** with a removable tip held in place in the holder by a self-acting taper. As in the case of shell and inserted-blade

reamers, the cutting elements are the only parts that need be made of high-speed steel. This type of drill is also available with a long holder or the holder shown may be used with a long tip.

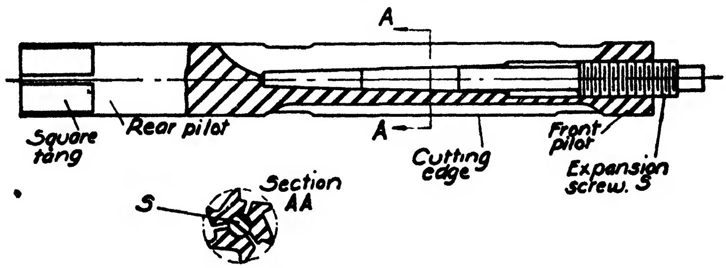

FIG. 10-35. Expansion Reamer.

Taper reamers are used for reaming tapered holes after they have been drilled. Roughing and finishing reamers for standard taper sockets are illustrated on page 186. The blades of the roughing reamer are notched to break up the chips. **Taper pin reamers** may be made with helical flutes as illustrated in Fig. 10-42; they may have straight flutes similar to the taper socket reamer, Fig. 10-40; or they may have special flutes. Taper pin reamers have a taper of ¼″ per foot of length, and are used for reaming holes for standard taper pins. **Bridge reamers,** Fig. 10-41, are made in both straight and spiral fluted types, and are used for aligning and reaming punched holes in structural and pressure-vessel work. They are principally used in portable electric or pneumatic tools. **Reaming** is far superior to **drifting** for this purpose particularly since it removes the metal around the punched hole, which is likely to be defective on account of the punching process.

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FIG. 10-36. Shell Reamer.

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FIG. 10-37. Arbor.

Burring reamers are used for removing burrs left in pipe by the process of cutting the pipe and are generally operated by a brace or by a special ratchet wrench.

128. Boring is a hole-enlarging process, but differs from core drilling and reaming in that the cutting edges do not follow the original hole, but generate a hole whose radius depends upon the distance of the tool point from the axis of rotation of the bar. Fig. 10-44 shows several representative **boring bars.** Bars employed in the drill press generally have a tapered shank to fit the spindle socket, with a free cutter end, as in bars 2, 3, and 4. Boring bars such as bar 1, Fig. 10-44, which are used in boring mills generally have a piloted or supported outer end which rotates in a supporting bushing and provides additional rigidity for the cutting process.

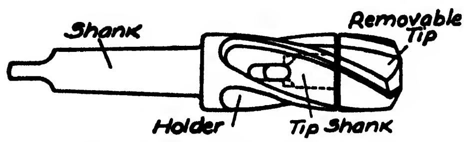

FIG. 10-38. Core Drill with Removable Tip.

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FIG. 10-39. Taper Roughing Reamer.

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FIG. 10-40. Taper Finishing Reamer.

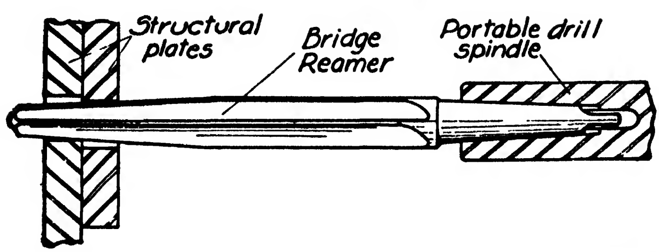

FIG. 10-41. Straight-fluted Tapered Bridge and Boiler Reamer.

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FIG. 10-42. Helical Taper Pin Reamer.

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FIG. 10-43. Left Hand Drill.

Bar 3 is the least expensive of the tools shown; the cutter is held by one set screw and adjusted and backed-up by the other. Bar 4 is a commercial

product; the cutter bits C and K are of square section with a central tapped hole for admitting the adjusting screw D. The split quill Q is clamped by set screw S, while the taper pin P prevents Q from rotating while D is

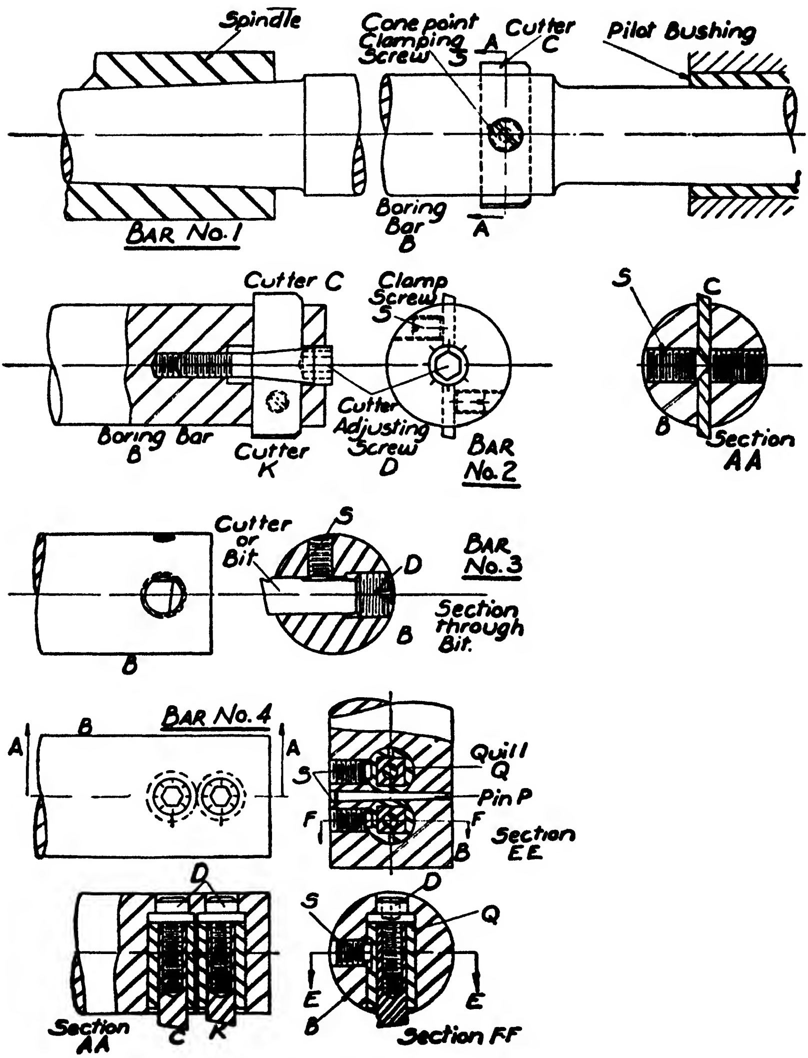

FIG. 10-44. Boring Bars.

adjusted. D is equipped with a graduated end so that definite increments of adjustment may be obtained. The two cutters shown are employed for progressive boring; K is the roughing, and C the finishing cutter.

Bars 1 and 2 are examples of two-lipped cutter bars. The cutter C in bar 1 is not adjustable for size, and is therefore employed either for rough-boring or as a facing cutter. Cutter C and cutter K of bar 2 may be adjusted for size by turning screw D and clamping with set screws S, but for accurate work the cutting edges should be ground after adjustment.

Counterboring, countersinking, and **spot-facing** are hole-enlarging operations that are generally performed on the drill press. A counterbored hole is cylindrical; a countersunk hole is conical; a spot-faced hole is one which is counterbored to a depth just sufficient to finish the surface. Spot-facing and counterboring may be performed with the same tools which are made with both straight and tapered shanks. Counterbores and most countersinks are equipped with pilots or guides to insure concentricity of

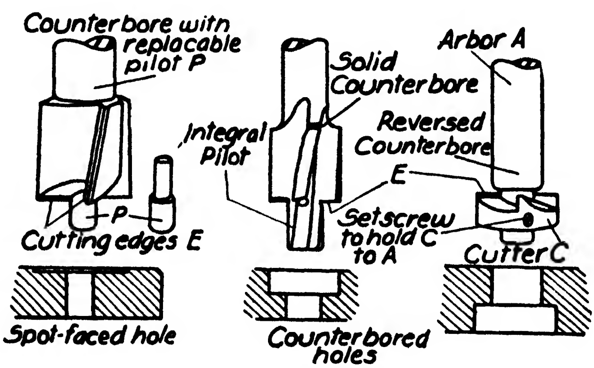

Fig. 10-45. Counter Boring Tools.

the counterbored and body holes. Replaceable pilots permit greater flexibility in the selection of counterbored diameters for given body hole sizes. The **reversed counterbore,** Fig. 10-45, is used when it is not feasible to counterbore from the top. The arbor is pushed through the hole, the counterbore or facing cutter attached from below, and the facing performed by feeding up. The **center drill,** Fig. 10-46, is a combination drill and countersink and is employed for drilling center holes for turning operations.

Center drilling can also be performed by first drilling a pilot hole and then countersinking with the center reamer. The **combination tool** illustrated in Fig. 10-46 is representative of the many special high-production tools available on order. The tool chamfers the corners of the hole and faces the top of the boss.

Fig. 10-47 shows a multi-cut or **sub-land drill** for drilling two-diameter holes in one operation. This drill is really two drills in one, constructed so that their separate cutting lips and flutes provide chip dis-

posal and permit resharpening of the cutting lips of the large barrel without injury to the small barrel.

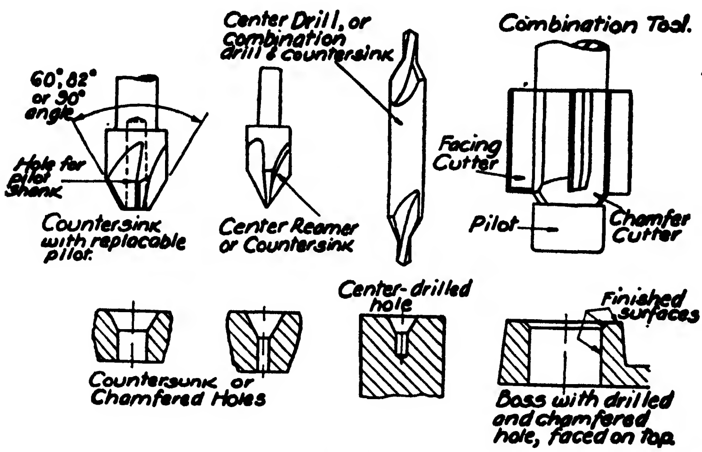

FIG. 10-46. Countersinking Tools.

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FIG. 10-47. Sub-land Drill.

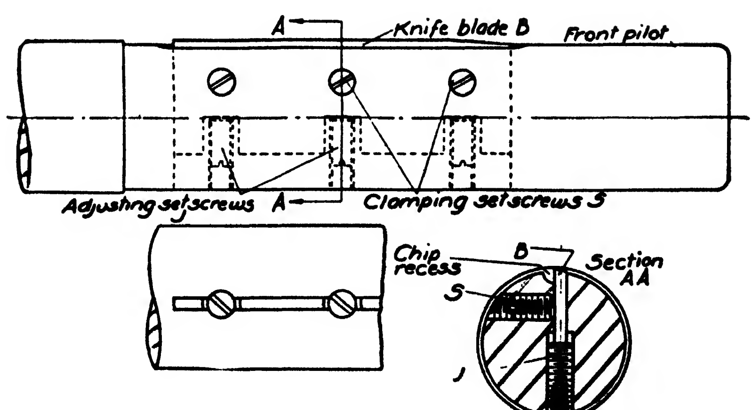


FIG. 10-48. Knife Reamer.

Fig. 10-48 shows a so-called **knife reamer** used for light finishing or aligning cuts. The **piloted reamer,** Fig. 10-49, is used where mul-

tiple hole alignment is required. (The depth of the cut and amount of material removed by the reamer are exaggerated for clarity.)

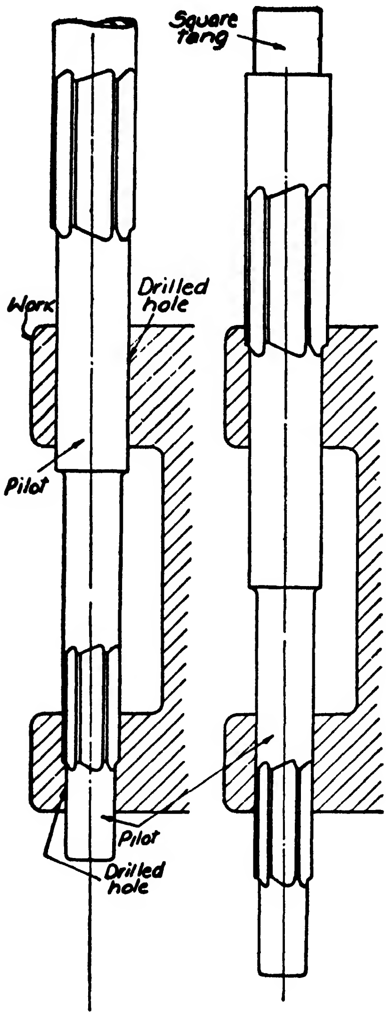


FIG. 10-49. Hand Reamer for Finishing and Aligning Drilled Holes.

129. Tapping is an internal threading process and may be accomplished by hand or by machine. Fig. 10-50 shows the necessary tools and the sequence of operations in threading a blind hole (one which does not go through the work). The bulk of the metal in a threaded hole is removed by a **tap drill** which has a diameter equal to or slightly greater than the root diameter of the thread. The threads may be cut by using several taps in succession. The **taper tap** has from seven to ten chamfered threads. The long chamfer serves as a guide in aligning the axes of the tap and the hole. The **plug tap** has from three to five chamfered threads and is the most frequently used tap, particularly in machine tapping. In hand tapping it is not as easy to start as the taper tap. The **bottoming tap** has a chamfer on the first thread only and is never used as a starting tap. It is only employed for finishing blind holes which require threading to the bottom.

Taps are made of carbon or high-speed steel. High-speed steel taps permit more rapid production and hold their cutting edge longer. Carbon steel taps give satisfactory service for occasional jobs and are much less expensive. Taps are made with two, three, or more flutes. The flute serves to form the cutting edge, and provides room for chips. Fig. 10-51 shows two forms of taps: the one on the left has no peripheral clearance, and is used for taps up to ½″ in diameter; the section at the right shows an eccentrically-relieved tap which cuts somewhat

more efficiently because of the clearance. Taps are made with squared shanks as in Fig. 10-50 for use with a tap wrench, or they may have straight cylindrical shanks as in Fig. 10-53 for use in chucks in machine tapping.

Through holes may be tapped with a taper tap if the length of the hole does not exceed twice its diameter; in such an instance the taper tap has too much cutting edge in contact at one time, which requires excessive tapping torque and may result in tap breakage. Plug taps or so-called **serial taps** may be used for long holes. Serial taps are made in sets of three, the first two of which are undersize in outer diameter. The first tap roughs out the thread; the second cuts the thread a little fuller; and the third is used for finishing and bringing the hole to size, thus distributing the work of tapping among three taps.

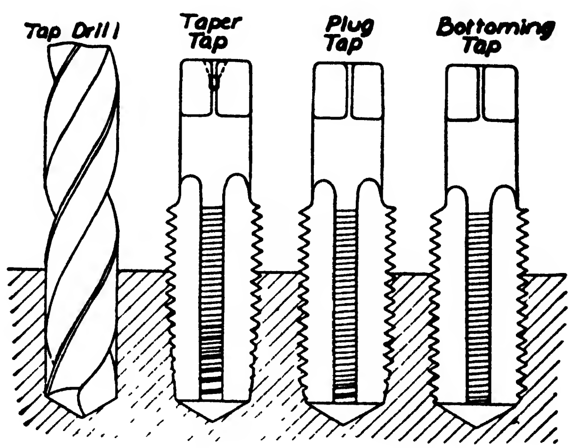


Fig. 10-50. Tapping Principles.

The magnitude of the **tapping torque** depends primarily upon the machineability and the amount of metal to be removed. In general, materials of a brittle nature are more easily tapped than those of a tough or fibrous character. The amount of material removed in threading a given hole is dependent upon the size of the tap drill hole. Tap drill diameters generally exceed the root diameter of the thread since it has been found that a thread which has an effective height of from 50% to 75% of the theoretical is amply strong for ordinary purposes, and that the tapping torque is thereby greatly reduced. Fig. 10-52 shows a 1½"—4 sharp V thread in which various sizes of tap drills are employed.

Fig. 10-53 shows a **spiral-pointed tap** which is employed for through-hole tapping. The angular cutting edge at the tip is ground so as to produce a long curling chip which shoots out ahead of the tap. The flutes

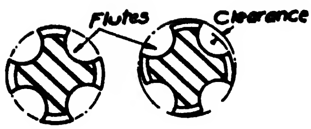


Fig. 10-51. Tap Forms.

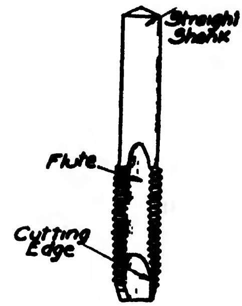


Fig. 10-53. Spiral-pointed Machine Tap.

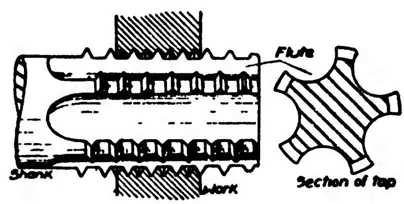


Fig. 10-54. Interrupted-thread Tap

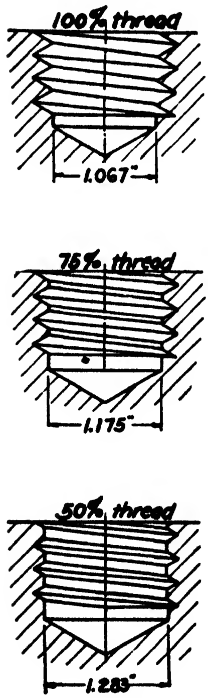


Fig. 10-52. Thread Percentages Obtained with Various Tap Drill Sizes.

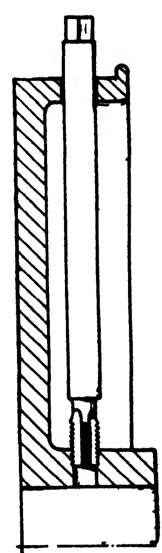


Fig. 10-55. Pulley Tap.

are quite shallow since little chip clearance is required, and spiral-pointed taps are therefore stronger than standard taps.

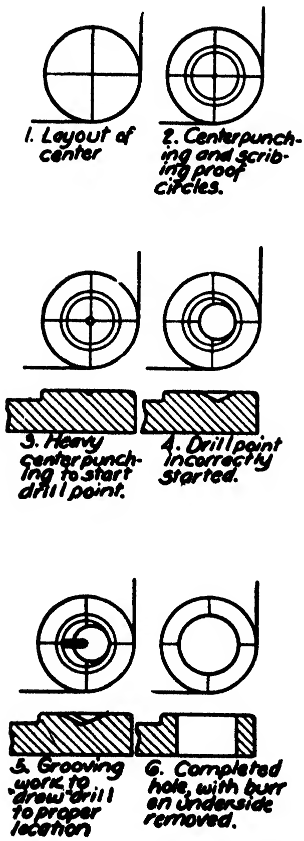


FIG. 10-56. Stages in Starting and Drilling a Hole in a Boss or Pad.

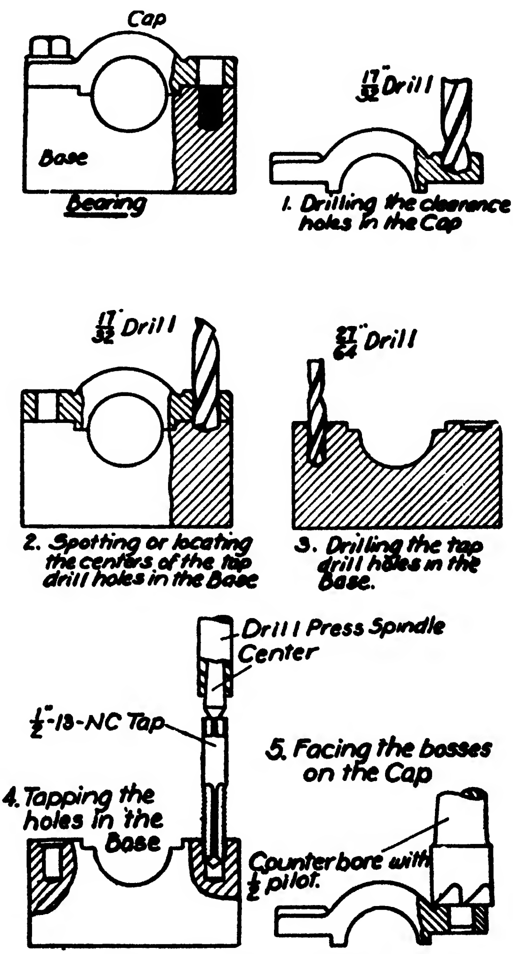


FIG. 10-57. Stages in Drilling and Tapping the Cap Screw Holes in the Cap and Base of a Plain Bearing.

Standard taps with right-hand **helical flutes** are sometimes used for machine-tapping blind holes. The rotation of the tap tends to force the chips out of the hole with an action similar to that of a twist drill.

Interrupted-thread taps illustrated in Fig. 10-54, are employed for tapping tough materials where torn threads are likely to result because the

chips may jam between two adjacent threads. This type of tap is not capable of as high production as those with a full complement of threads.

Fig. 10-55 shows a **pulley tap** for threading oil cup or set screw holes in pulleys. The shank has a diameter equal to the thread diameter, and serves to guide the tap.

The so-called **tapper tap** is similar to the taper tap of Fig. 10-50, but has a long cylindrical shank whose diameter is somewhat less than the root diameter of the thread. It is used for tapping nuts in large quantities in semi-automatic machines. As the nuts are threaded, they are run up

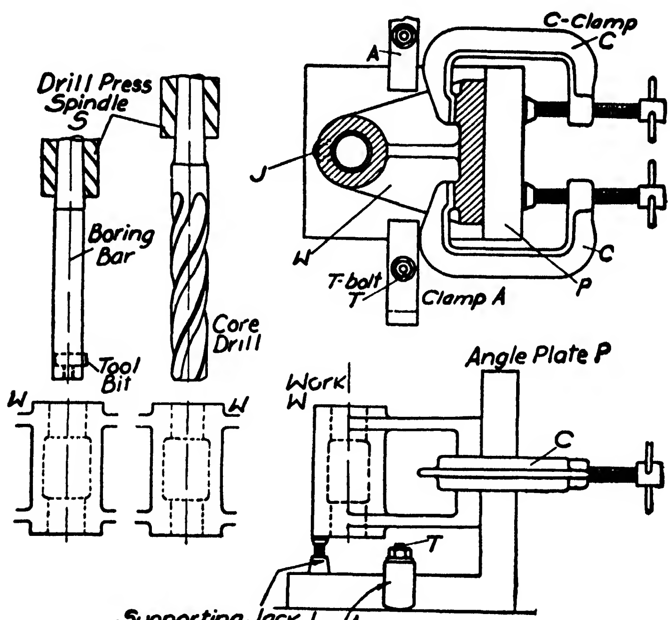


FIG. 10-58. Core Drilling and Boring the Bearing Hole in a Bracket or Frame.

on the shank until the tap is full, and are then removed by taking the tap out of its holder or chuck.

Collapsible taps in the larger sizes are employed in turret lathe and chucking machine work. The tap consists of a body carrying a number of blades with cutting edges which may be readily retracted. This feature permits removal of the tap after the threading operation is completed without the necessity of reversing the direction of rotation and screwing the tap out of the hole.

130. Fig. 10-56 illustrates the stages in drilling a hole in which the center is located by the intersection of a pair of scribed lines. When the

In ordinary turning, the carriage need not move an exact distance for each turn of the spindle. If the lead screw is employed for turning, it

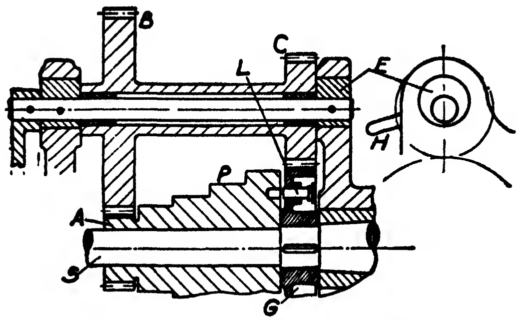
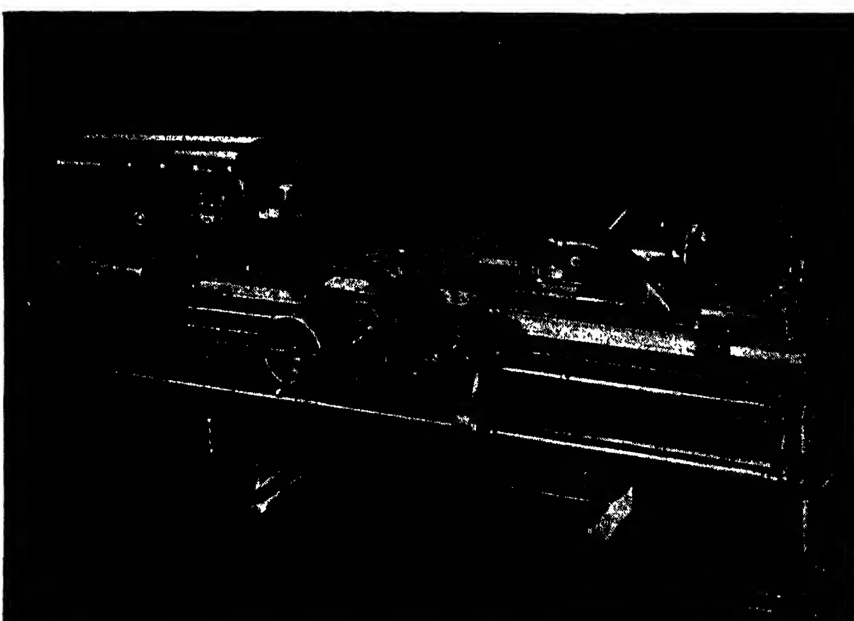


FIG. 11-3. Lathe Back Gears in Engagement.

may wear and become inaccurate so that precision threading can no longer be accomplished. For ordinary turning, the **feed shaft** *SS* moves



The American Tool Works Co.

FIG. 11-4. Selective Geared Head Engine Lathe.

the carriage longitudinally through bevel and worm gearing behind the apron (the feed gearing in the apron is not illustrated or described). In

some lathes the feed shaft is driven by a belt or cone pulley, *JJ* and *KK*, and in others such as the lathe of Fig. 11-1, by selective gearing.

The feed shaft also furnishes mechanical feed for the cross-slide screw so that transverse facing operations may be performed under power. Both the carriage and cross-slide can of course be hand fed, the former by the carriage hand wheel, and the latter by the cross-slide screw crank. The compound rest, however, has no power feed and must be operated by the crank on the compound rest screw.

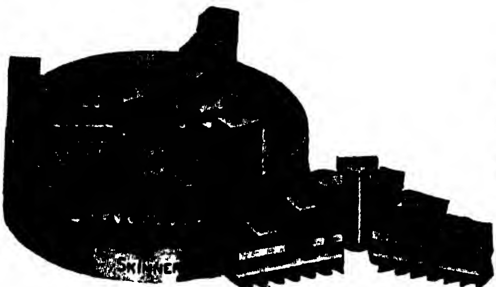
133. The **size** of a lathe is determined by the diameter and length of work that may be swung between centers. A 14" x 54" lathe, for example, will handle parts that are 14" in diameter and 54" long. Lathes of comparatively small swing are generally termed **bench lathes. Gap lathes** are large engine lathes with a space or gap in the bed at the headstock which will permit work to be handled, particularly in facing operations, that would exceed the capacity of the ordinary engine lathe of similar proportions. Very large lathes, particularly those employed in ordnance manufacture, are often made without legs with a bed mounted directly on a concrete base. **Geared head lathes** similar to Fig. 11-4 are driven by a constant speed motor, and all spindle speed changes are obtained by shifting gears in the headstock.

134. There are three important methods of holding and rotating work in engine lathes, which may be referred to as turning between centers; chuck work; and faceplate work. In **turning between centers,** the work is supported by the 60° conical points of the live and dead centers, turns with the live center, and on the dead center. The work must therefore have 60° center holes in each end, machined by using a pilot drill and a 60° countersink, or the center drill illustrated in Fig. 10-46. (The function of the drilled hole is to insure contact on the sides of the conical hole and not at the extreme point.) The work is rotated by a **lathe dog,** illustrated in Fig. 11-24, which is clamped to the work by means of a set screw. The tail of the dog fits loosely in a slot in the lathe faceplate and turns with it. In many lathes, the **faceplate** *F* screws on the spindle nose *N* as illustrated in Fig. 11-2. In modern heavy-duty lathes, the faceplate is seated and keyed on a standard tapered spindle nose, and is drawn on and held in place by a "pull-on" nut engaging external threads on the hub of the faceplate.

A **chuck** is a rotating vise which may be attached to the spindle of a machine. There are two important varieties of lathe chucks, independent and universal. In general, the **independent chuck** has four jaws each of which is separately actuated and adjusted. It may be employed for almost any type of work, cylindrical, square, or irregular. In turning cylindrical work, it is necessary to adjust the jaws very carefully, and test

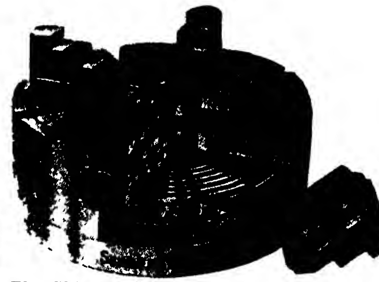
the concentricity of the work and spindle axes with some form of indicator. When a four-jaw independent chuck is employed for repetitive work, only two adjacent jaws are actuated as each new part is placed in the chuck after the initial adjustment and alignment of the jaws has been obtained.

Three-jaw universal or self-centering chucks are employed for cylindrical and hexagonal bar stock. A universal chuck is illustrated in



The Skinner Chuck Co.

FIG. 11-5. Three-jaw Universal Chuck with Two Sets of Jaws.



The Skinner Chuck Co.

FIG. 11-6. Combination Chuck.

Fig. 11-5. The jaws are simultaneously advanced or retracted by turning the scroll plate in which the jaw teeth fit. On account of the curvature of the scroll, it is necessary to have separate sets of jaws for inside and outside clamping, in contrast to the independent chuck where the jaws may be reversed. Fig. 11-6 illustrates a **combination chuck** which combines an independent chuck for holding odd-shaped work; a universal chuck for self-centering and gripping round or square work; and a chuck for handling duplicate work. Fig. 11-7 shows a **two-jaw universal chuck** with jaws to which special adapters may be fitted. This chuck is employed principally in turret lathe work.

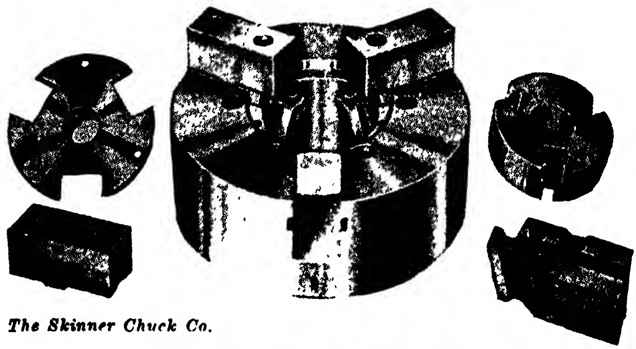
The Skinner Chuck Co.

FIG. 11-7. Two-jaw Universal Chuck.

Independent and universal chucks may be attached to a threaded adapter which screws on the spindle nose. These chucks may also be obtained with adapters to fit the heavy-duty taper spindle nose, and are driven in the same manner as the faceplate shown in Fig. 11-2. The chuck is drawn on the spindle nose by the engagement of the "pull-on" nut with the externally-threaded hub of its adapter.

Fig. 11-8 illustrates an **air-operated chuck.** The chuck body with two jaws and work-holding adapters in place is shown in the center of the figure. At the right is shown the third jaw without the adapter in place, and above it is the actuating wedge which closes and opens the jaws by

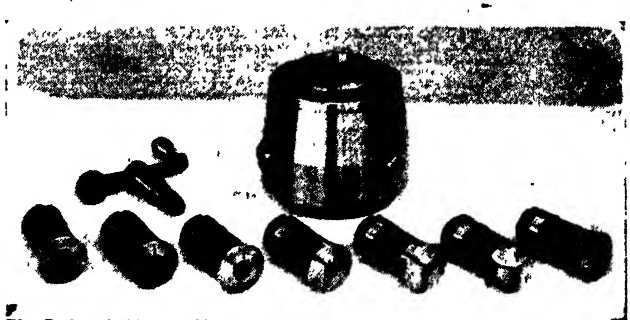
moving parallel to the chuck axis. The actuating wedge is threaded so that a draw-rod may be attached. The other end of the draw-rod is attached to a piston operating in an air cylinder which is attached to the lathe headstock. The piston is double-acting so that the chuck jaws may be both



The Skinner Chuck Co.

FIG. 11-8. Air-operated Chuck.

opened and closed by the action of compressed air. The chuck is operated by a valve convenient to the machine operator. Air and oil operated chucks are generally employed for production work, as in turret and chucking lathes.



The Ledge & Shipley Machine Tool Co.

FIG. 11-9. Draw-in Chuck, Spring Collets, and Wrench for Bar Work.

Fig. 11-9 illustrates a draw-in chuck and collets for bar work. This chuck is designed to fit on the heavy-duty spindle nose if the live center is removed. The collets, which are of various sizes, fit in the chuck and are clamped with a removable key or wrench. Drawing in the spring collet forces its outer surface against the taper on the inside of the chuck; releasing the collet causes its jaws to open by their spring action as illustrated in Fig. 11-10. Bars of any length may be held in the chuck, extending

entirely through the hole in the spindle if necessary. Collets for all standard sizes of circular rod are available as well as collets for hexagonal bar stock and cylindrical metric sizes.

Magnetic chucks of both the electrically-actuated and the permanent magnet type may also be employed on the lathe. Fig. 11-11 shows a permanent magnet type of chuck held on a faceplate by clamps. This type of chuck is adapted to work which is difficult to hold in chuck jaws, either on account of its shape or because the pressure of the jaws may distort the work.

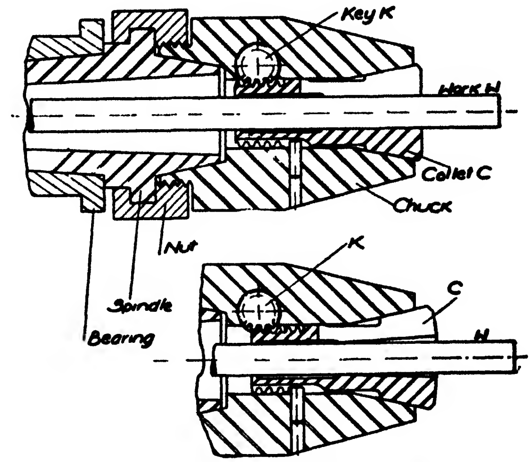


Fig. 11-10. Construction and Operation of Collet Chuck.

Lathes are generally equipped with two faceplates; one small plate for driving lathe dogs, and a large plate with slots so that work may be attached by means of clamps and bolts. Some applications of faceplate work will be described later.

Brown & Sharpe Mfg. Co.

Fig. 11-11. Permanent Magnet Type Rotary Chuck in Use on Lathe.

135. Fig 11-12 illustrates the essential operations in turning cylindrical work on a lathe. The work shown is a cylindrical bar of cast iron. The casting is about 3/16" larger in diameter, and has been previously cut to a length 1/16" greater, than the finished part. The first operation is not illustrated, and consists of centering each end of the casting and drilling center holes with a center drill. See Fig. 10-46. A bent-tail

lathe dog, Fig. 11-24, is clamped to one end of the bar which is placed between the live and dead centers of the lathe. The lathe dog tail fits loosely in the slot in the faceplate and serves to drive the work. The dead center is lubricated with some substance such as white-lead and oil, and adjusted to the work by turning the tailstock sleeve screw handwheel so that the work will rotate on the dead center without any perceptible looseness or "shake." The tailstock sleeve is then clamped.

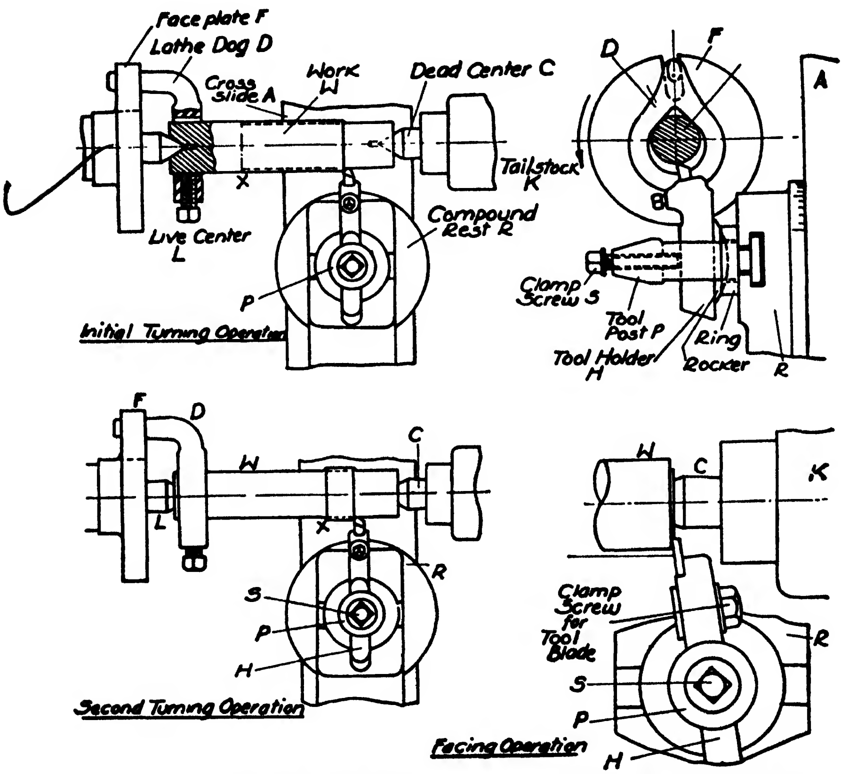


FIG. 11-12. Turning and Facing Cylindrical Work in an Engine Lathe.

A **straight-shank turning tool** with an inserted tool bit, Fig. 11-13, is placed in the tool post and adjusted by means of the supporting rocker so that the tool point or cutting edge will be very slightly above center. The tool post screw is tightened so as to clamp the tool holder in place.

Fig. 11-12 shows the **initial rough-turning operation** about half completed. A cut sufficiently deep to get under the casting scale is taken, but at least .015" to .025" must remain for finish turning. The depth of cut is set by adjusting either the cross-slide or the compound rest, and the

operator starts the longitudinal feed of the carriage by turning the carriage hand wheel. As soon as the operator observes that the feed and cut are satisfactory, he engages the power feed for the carriage, and the turning continues until point X is reached. At this point the lathe spindle rotation and the feed are stopped, the dead center is withdrawn, the work is removed from the centers, and the carriage is returned by hand to its initial position. The lathe dog is taken off the end of the bar and placed on the other end of the work which is then replaced between the centers, thus reversing the work end for end. Without disturbing the tool setting, the balance of the bar is then rough-turned as shown in the second turning operation in Fig. 11-12. The second roughing cut is run slightly past point X to be certain that no ridge remains.

Armstrong Bros. Tool Co.

FIG. 11-13. Straight-shank Turning Tool with Inserted Tool Bit Taking a Heavy Cut.

The same procedure is followed for the **finishing cut.** The tool is generally resharpened or stoned for this operation. A trial finishing cut is taken; this cut is just long enough so that the bar diameter may be measured, which may be done by using outside calipers, vernier calipers, or a micrometer, depending upon the degree of precision required. For example, the operator takes a short finishing cut (probably not over an eighth of an inch in length), stops the lathe, moves the carriage back, and measures the diameter turned. If this diameter is found to be .004″ oversize, the cross-slide is moved in about .002″, employing the graduated dial on the cross-slide screw. Another trial cut is taken and the work is again measured. If the

Armstrong Bros. Tool Co.

FIG. 11-14. Right-hand Offset Side Tool Facing a Casting.

diameter is correct, the longitudinal power feed of the carriage is engaged, and a finishing cut is taken for about two-thirds of the length of the bar. The work is then reversed end for end, and the remainder of the bar length is finish turned with the same tool setting. The finished surface on the second finishing cut is generally protected by inserting a piece of copper or brass between the work and the point of the lathe dog set screw.

After the cylindrical surface of the work is finished, the turning tool is removed, and a **right-hand offset side tool,** Fig. 11-14, is substituted. The carriage is set in the approximate position required for the end facing cut and clamped. The compound rest is set around at an angle and used to provide adjustment for the depth of cut. The cross-slide is employed to feed the tool towards the axis of the work, and is generally hand operated because the distance to be traversed is so short. After one end is squared, the work is reversed between centers, the other end squared, and the bar brought to correct length. The facing or squaring operation generally leaves a burr at the center holes, which must be removed by filing at the bench.

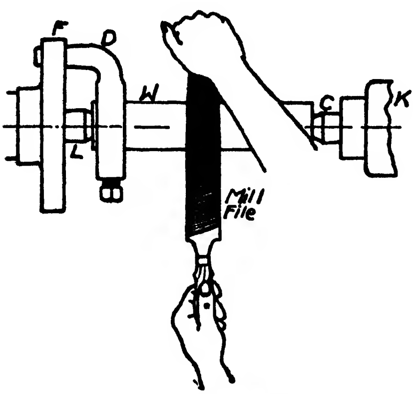


FIG. 11-15. Lathe Filing.

In some instances it is necessary to obtain a smoother finish than that provided by turning. In such cases finishing by filing and polishing with emery cloth may be resorted to. Fig. 11-15 illustrates the filing operation. An ordinary single-cut mill file is employed, and the work rotates at a higher speed than is employed for turning. (It is of interest to note that the *left-handed* method of holding the file shown in Fig. 11-15 is much safer than the conventional method in which the left hand holds the tip and the right hand the handle of the file, and in which the rotating dog may tend to catch the sleeve of the operator.) When a filed finish is required, the operator generally turns the bar 0005″ to .001″ oversize for filing allowance. Too much filing may destroy the precision of the bar; too little will not permit the removal of the turned ridges.

In many instances the facing or squaring operations are performed *before* the turning operations, particularly if it is necessary to remove any appreciable amount to bring the bar to proper length. If a large amount of metal has been removed in facing, it may be necessary to redrill the center holes to provide sufficient bearing area for the subsequent turning operations.

In machining long bars of small diameter, the bar has a tendency to spring away from the cutting tool so that a truly cylindrical surface cannot be procured. For such work some form of auxiliary support other than the use of the centers is required. Fig. 11-16 illustrates two such methods. The **follower rest** is a support that is bolted to the carriage with bearing blocks that can be adjusted to fit the turned surface.

Whenever the bar has several diameters so that a follower rest cannot be employed, a **steadyrest** may be used. In this case it is necessary

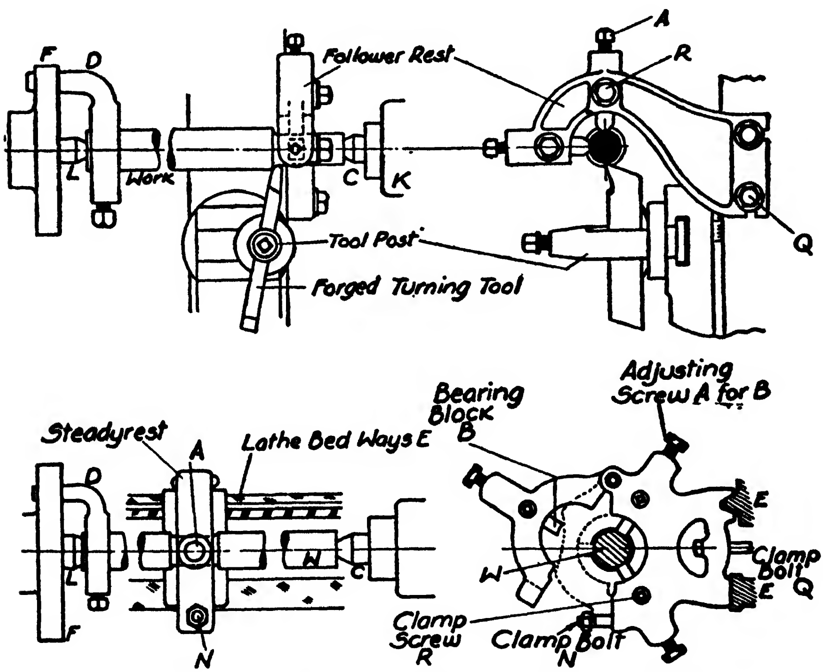


FIG. 11-16. Applications of Follower Rest and Steadyrest.

to turn a small portion of the bar to size, which can generally be done by taking light cuts. The steadyrest is clamped to the lathe bed, and its bearing blocks are adjusted to the turned surface or "seat" on the bar. In this application the steadyrest acts as a center bearing, but is not as effective as the follower rest which provides a support immediately to the right of the turning tool, or practically at the point where the cutting force is exerted.

136. Tapered or conical work may be turned in the lathe by five methods, three of which are illustrated in Fig. 11-17. A capable mechanic can turn an approximate taper by simultaneously hand-operating the longi-

tudinal carriage feed and the transverse cross-slide feed but the surface produced will not be precise. Short tapers may be turned by using a broad-

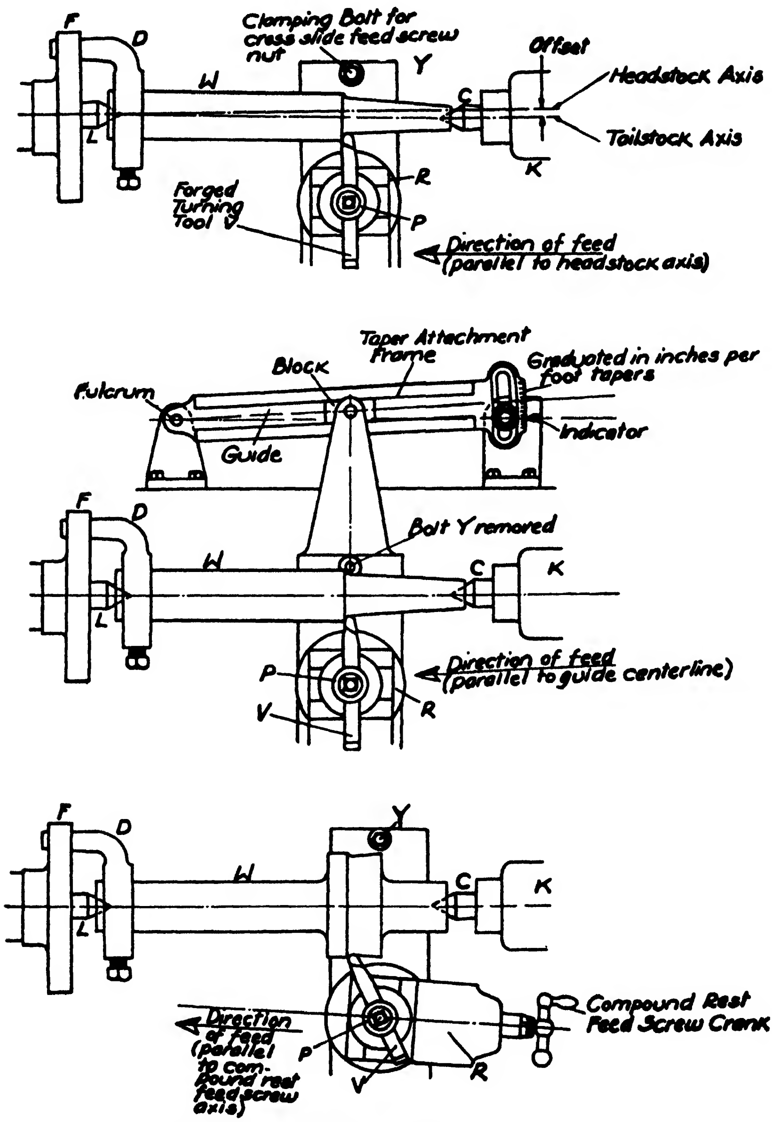


Fig. 11-17. Taper Turning on the Lathe.

nosed turning tool whose cutting edge is set at an angle to the center axis. The live center of the lathe may be refinished or corrected in this manner.

The first method shown in Fig. 11-17 necessitates **setting-over the tailstock** an amount equal to one-half the taper, based upon the actual length of the stock. (As previously explained, the tailstock is mounted on a cross-keyed saddle which is fitted with adjusting screws so that adjustment perpendicular to the spindle axis may be made.) The set-over method is not applicable to large tapers since the centers will not fit properly in the center holes.

The **taper attachment method** is accurate but requires a taper-turning attachment on the lathe. In this method the clamping bolt for the cross-slide feed screw nut is removed so that the motion of the cross-slide is no longer controlled by its screw, but is guided by a block moving in the taper attachment guide. The tool adjustment and setting is effected by the compound rest.

Another method of turning tapers, particularly large tapers, is to set the compound rest at the required angle, clamp the carriage in place, adjust and set the tool by using the cross slide, and cut the taper by hand-feeding the compound rest.

137. Fig. 11-18 illustrates the manufacture of a brass bushing. The stock is a piece of cylindrical brass rod about 1/8" oversize in length and diameter, and is set up in an independent jaw lathe chuck. As the stock has a finished exterior, a **dial indicator,** held in the tool post, may be employed to determine its axial alignment with the spindle axis. (If the stock were a casting, it would probably suffice to true it by using a piece of chalk as illustrated in Fig. 11-26.) If the stock does not run approximately true, the chuck jaws are adjusted until the alignment is correct. The indicator is then removed and a **center-spotting tool** substituted, whose tool bit is ground so that it will cut a conical depression with an included angle of about 118°, to serve as a starting "spot," for the drill. The next operation is that of **drilling** the hole. A drill that is about 1/16" undersize is employed and is supported at the cutting end by the spot, and at the other, by the dead center. Rotation of the drill is prevented by the lathe dog attached to it. The drill is fed by turning the tailstock hand wheel.

After drilling, the bushing is **bored** to size by using the single-point boring tool shown. (Boring bars such as shown in Fig. 11-27 might also be employed.) Boring corrects any misalignment of the drilled hole and the spindle axis. After boring, the bushing is faced (not shown) either by hand or power feeding of the cross-slide, and is removed from the chuck. A mandrel, Fig. 11-19, is then pressed into the bushing in an arbor press as illustrated in Fig. 11-28, to permit the exterior of the bushing to be finish-turned and to square the other end and bring the bushing to length.

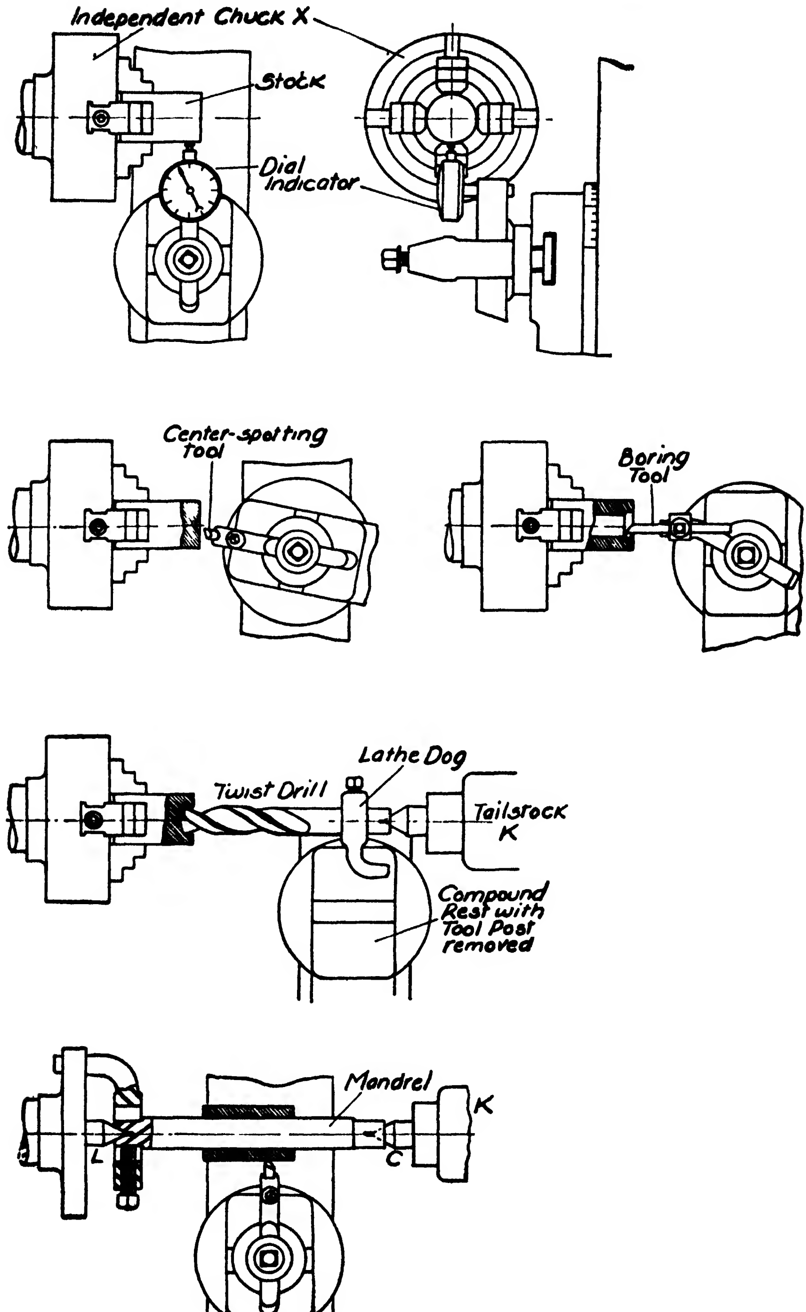


FIG. 11-18. Turning a Bushing in the Engine Lathe.

138. Figs. 11-19, 11-20, and 11-21 illustrate three types of mandrels. The **solid mandrel** has a slight taper to permit it to be pressed into hollow work, and is made of hardened and ground steel. The **expansion mandrel** is made to fit a small range of sizes; the mandrel proper is sufficiently tapered so that it will expand the sleeve to permit it to grip the work. There are generally several sizes of sleeves for each mandrel. The expansion mandrel is usually preferred to the solid mandrel in the larger sizes.

The **nut mandrel** is a specialized device employed for turning a number of parts at one time, and is generally made for a definite job.

Figs. 11-23, 11-24, and 11-25 illustrate several types of **lathe dogs.** The heavy dog with the flat-sided tail is employed for milling machine work. The two-screw lathe dog is used for square and hexagonal stock, although it may be used for cylindrical work.

Fig. 11-22 illustrates a **rotating dead center** often employed for heavy turning operations. It has a tapered shank for insertion in the tapered hole in the tailstock sleeve. The center proper is carried by a shaft which rotates in ball or roller bearings, and the sliding usually present between the work and the dead center is thereby eliminated since the center turns with the work.

139. Fig. 11-26 shows a series of operations on a casting with a cored hole. The casting is clamped in an independent-jaw chuck and tested for alignment by a piece of chalk held in the operator's hand. Since the casting has a cored hole, it is necessary to use a three- or four-lipped chucking drill for **rough-boring** the hole which is thereby brought to within 1/32″ of its true size. (The illustration shows a tapered shank chucking drill held in the tailstock sleeve; in many instances it might be advisable to support the drill by the dead center, and drive it with a dog since it will thereby follow the cored hole and result in less strain on the drill.) The hole is then brought to within .005″ of size by using an end-cutting or **rose reamer.** The front face and hub of the casting are then rough and finish-faced, generally by a transverse power feed, and the casting is removed from the chuck. The hole is then finished or hand reamed to size at the bench, a mandrel is pressed into the hole, and the remaining surfaces turned and faced.

140. As previously described, **thread cutting** is performed on an engine lathe by gearing the lead screw to the spindle. Most lead screws have an Acme thread form, and are single-threaded, right-hand, 1/6″ pitch. If a six-pitch right-hand thread is to be cut, it is necessary to set up the lathe so that gear *D* (Fig. 11-2) drives gear *U* through gear *K*, with gears *CC* and *FF* of the same size, and a single idler *DD* (instead of the compound gear *DD-EE*). In this arrangement the lead screw will turn once for

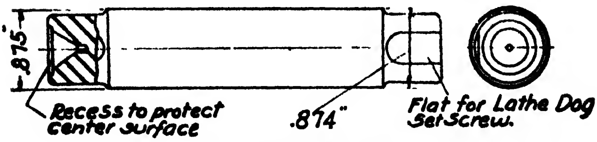


FIG. 11-19. Solid Lathe Mandrel.

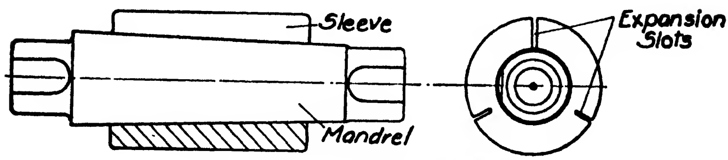


FIG. 11-20. Expansion Mandrel.

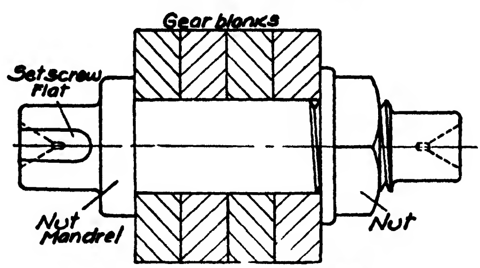


FIG. 11-21. Nut Mandrel.

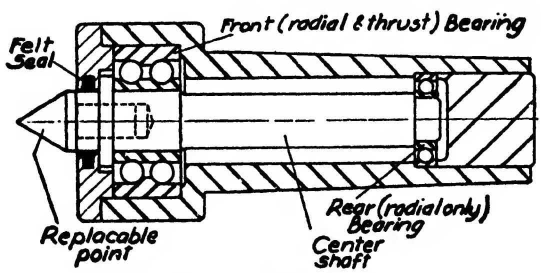


FIG. 11-22. Rotating Dead Center.

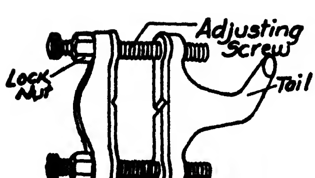


FIG. 11-23. Two-screw Lathe Dog.

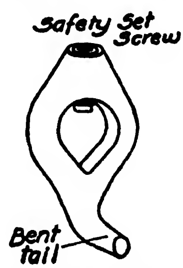


FIG. 11-24. Bent Tail Safety Set Screw Lathe Dog.

FIG. 11-25. Heavy Lathe or Milling Machine Dog.

every turn of the spindle and advance the carriage 1/6" towards the *head-stock* for every turn of the spindle. If the thread to be cut were left-hand, of the same pitch, the same change gears would be employed, but the re-

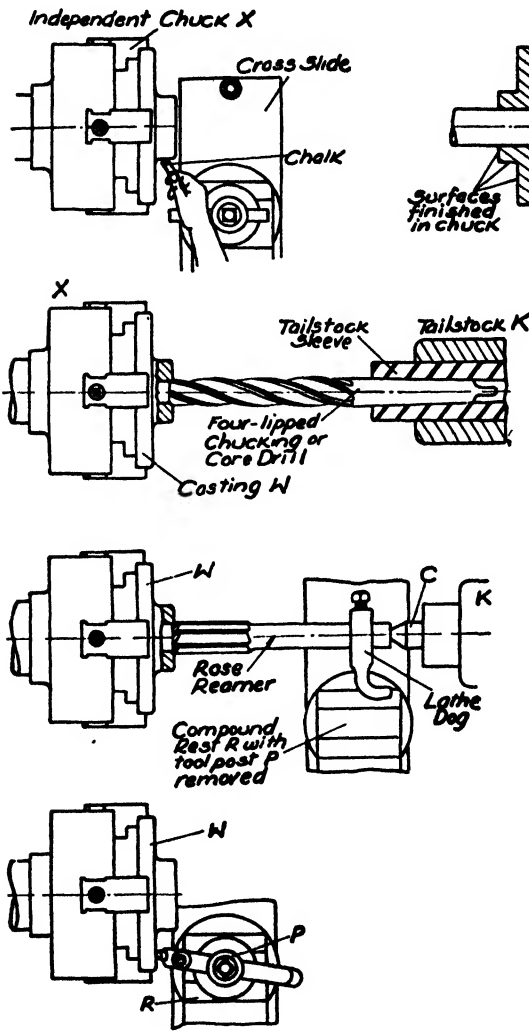
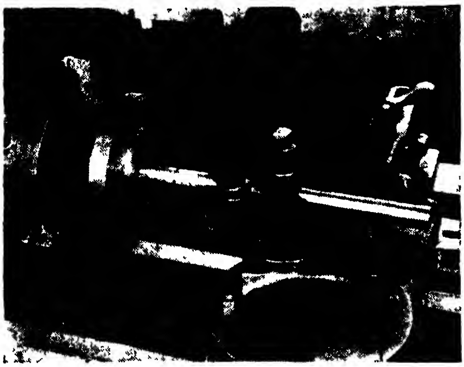


FIG. 11-26. Finishing a Casting with a Cored Hole.

versing plate would be shifted so that the drive to the stud is through gears *D, J, K,* and *U,* thus causing the stud and the lead screw to turn in a direction opposite to that of the spindle, and causing the carriage to move 1/6"

towards the *tailstock* for every turn of the spindle. If a screw with a pitch other than 1/6" is to be cut, the lead screw and spindle speeds must differ.


Armstrong Bros. Tool Co.
FIG. 11-27. Boring Tool.

For example, if a screw with a pitch of 1/12" is to be cut, the carriage must advance 1/12" for every turn of the spindle, and since the lead screw has a pitch of 1/6", it must therefore turn at one-half the speed of the spindle. Similarly, if a thread with a pitch of ½" is to be cut, the lead screw must turn three times as fast as the spindle and thus provide a carriage motion of ½" for each spindle turn.

Change gears *CC, DD, EE,* and *FF* may be interchanged to

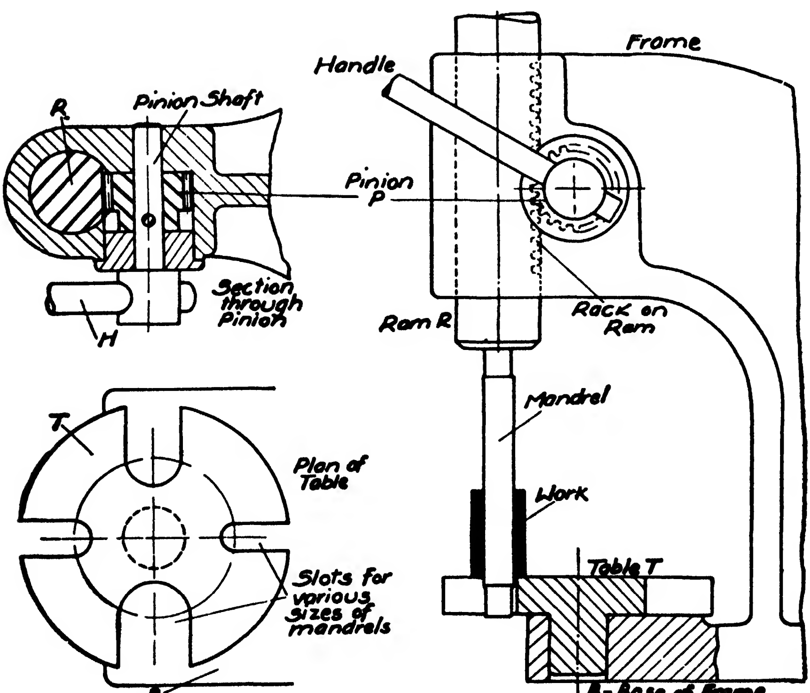


FIG. 11-28. Pinion and Rack-operated Hand Arbor Press.

effect this variation between the lead screw and spindle speeds. Gears with the following tooth numbers are often supplied as change gears: 13, 15, 18, 20, 22, 24, 26, 30, 36, 42, 50, 86, 100, 127. If a 7/8″-9-N.C. thread is required, it will be necessary for the lead screw to turn twice with a carriage advance of 1/3″, while the spindle turns three times, and thereby provide a carriage advance of 1/9″ per revolution of the spindle. In this case any pair of gears, such as 30 and 20, or 36 and 24, which have a 3 to 2 ratio, may be used for the change gears *FF* and *CC*, and connected by a single idler *DD* of any number of teeth.

Many thread pitches may be cut by employing a single idler but the use of the compound gear idler *DD-EE* is sometimes necessary. For example, in cutting a ½″-13-N.C. thread, a combination of 13 spindle turns and 6 lead screw turns are required. As there are no gears which will give a 13 to 6 ratio directly, it is necessary to employ a compounded drive as follows: *CC*-24; *EE*-26; *DD*-15; *FF*-30. Gears *EE* and *DD* are placed on a compound gear bushing which has a plain bore but has integral keys on its exterior surface, thus causing gears *EE* and *DD* to turn as a unit on stud *HH*. The speed of the compound will be $13 \times 24/26 = 12$ r.p.m. The lead screw speed will be $12 \times 15/30 = 6$ r.p.m.

The 127 tooth gear is employed for cutting threads with metric pitches. For example, in cutting a thread having a lead of 3 millimeters which is equivalent to 25.4/3 threads per inch, the spindle must turn 25.4 times while the lead screw turns 18 times. The proper ratio between the two is obtained by using the following change gears: *CC*-100; *EE*-20; *DD*-18; *FF*-127.

Fig. 11-29 shows the operation of **cutting a sharp V thread.** The center gage is employed to set the threading tool perpendicular to the axis of the work. In this illustration it is necessary to withdraw the threading tool before it reaches the end of the thread groove resulting from a previous cut. Fig. 11-30 shows a screw with a run-out groove in which the cutting tool is permitted to run clear of the thread, and thus eliminate the possibility of breaking the tool point.

There are **three methods of cutting threads** illustrated in Fig. 11-31. In the first method the tool point is fed perpendicularly to the work axis, every cut has the same profile, and the edges of the cutting tool take progressively larger cuts. In this method it is impossible to have any top or side rake on the cutting tool. In the second method the compound rest is set at an angle of 60° to the spindle axis, and practically all of the cutting is done on one side of the thread. (The final finishing cut generally cleans up both sides as illustrated.) This method permits the tool to have some side rake, and results in cleaner cutting. The third method employs an indexing tool as illustrated in Fig. 11-32, in which each tooth takes a successively

deeper cut. Only the last cutting edge need be really accurate, and it will remain so because it has little material to remove.

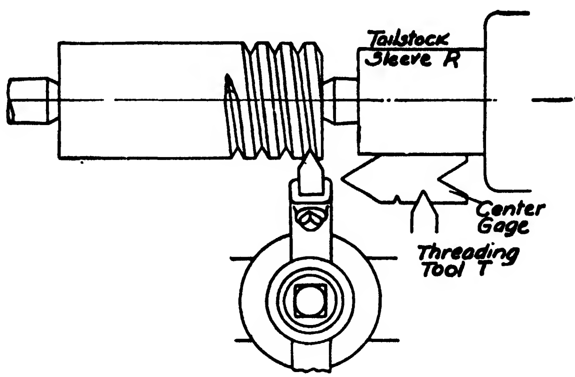


FIG. 11-29. Cutting a Sharp "V" Thread on a Lathe.

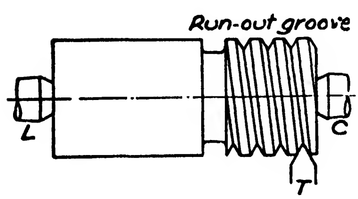


FIG. 11-30. Thread Cutting, Employing a Run-Out Groove.

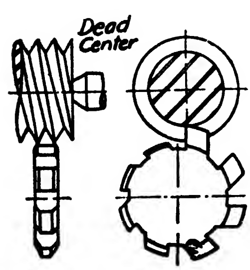


FIG. 11-32. Indexing Tool for Thread-cutting.

FIG. 11-31. Three Methods of Cutting Sharp "V" Thread Profiles.

Figs. 11-33 and 11-34 show the successive operations required in cutting a **double-threaded Acme screw.** After one thread groove is completed by successive cuts as in Fig. 11-33, the other is started 180° away

from it. This may be accomplished in modern geared head lathes by employing the thread-chasing dial: and in change gear lathes by disengaging

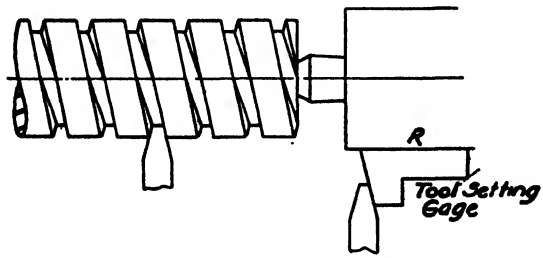


FIG. 11-33. Cutting a Double-threaded Acme Screw —First Operation.

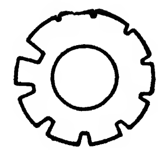


FIG. 11-35. Gage for Checking Size and Proportion of Acme Threading Tool Point After Grinding.

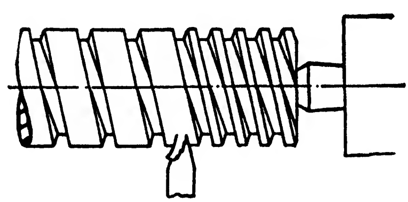


FIG. 11-34. Cutting a Double-threaded Acme Screw—Second Operation.

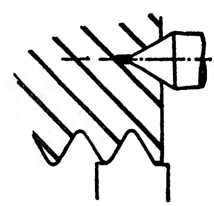


FIG. 11-36. Cutting Whitworth Threads.

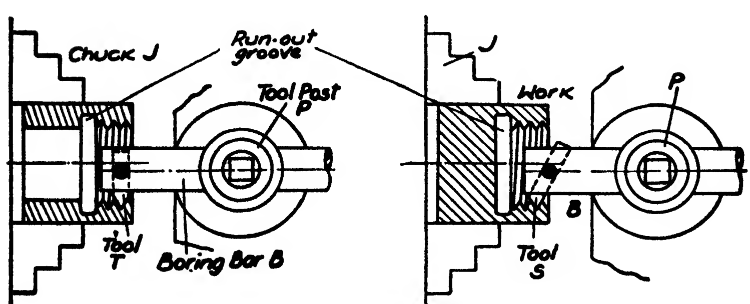


FIG. 11-37. Cutting Internal Threads on the Lathe.

the change gearing, rotating the lead screw 180°, and re-engaging the gearing. Fig. 11-33 also shows the method of setting the thread-cutting tool.

Fig. 11-36 shows **Whitworth form threading.** A different form tool is required for each pitch. American Standard and Acme thread forms

require tools of different proportions for each pitch, but they may be easily hand ground because all the cutting edges are of straight-line form.

Internal threading, illustrated in Fig. 11-37, is accomplished by inserting a threading tool bit in a boring bar. The illustration shows why different boring bars are required for through holes and for blind holes. Internal threading is greatly facilitated if a deep, long run-out groove is employed. The threading tool is set by fitting it in one of the thread notches of a center gage while the center gage is held against the face of the work.

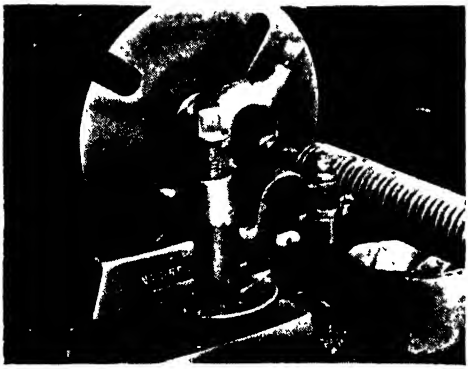


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Fig. 11-38. Spring Threading Tool Holder for Smooth Cutting on Tough Materials.

Fig. 11-38 shows a gooseneck **spring threading tool** which is generally employed on tough materials such as alloy steels. This tool is used to permit smooth cutting by eliminating chatter. Fig. 11-39 shows a threading tool holder with a **circular form tool** which may be resharpened by grinding the top face of the tool without changing its form. After each resharpening operation, the tool must be reset by adjusting the knurled-head screw shown so that the plane of the top face coincides with a horizontal plane through the axis of the work. In some instances a **multi-point chasing cutter** of the same general design is employed. For occasional jobs in fine-pitch threading, a tap of the pitch required, whose diameter is smaller than the diameter of the threaded hole, may be held in the tool post with its axis parallel to the spindle axis and employed to cut or chase internal threads.

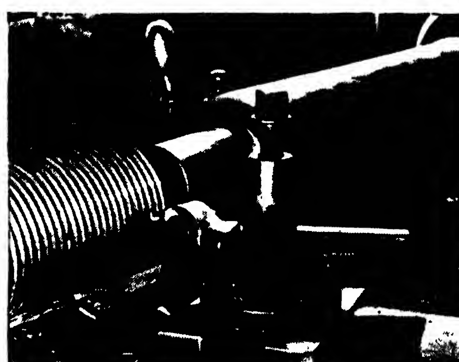

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Fig. 11-39. Threading Tool with Circular Form Cutter.

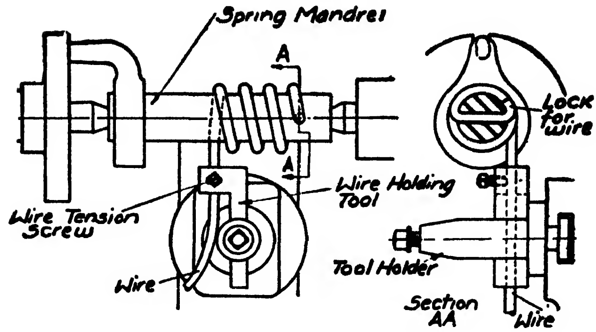

FIG. 11-40. Winding a Helical Compression Spring on an Engine Lathe.

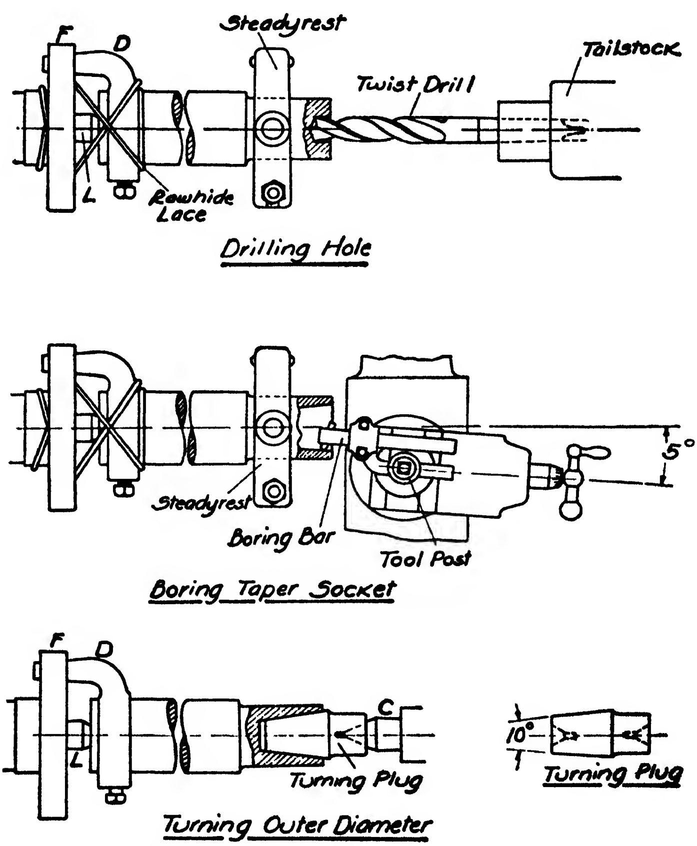

FIG. 11-41. Machining a Shaft with a Tapered Hole in One End.

141. Spring winding may be done on a lathe by employing the lead screw to provide a constant lead for the spring. A special tool holder to furnish the necessary tension on the spring wire and a mandrel to suit the inner diameter of the spring are required. Fig. 11-40 shows a helical compression spring in the process of manufacture. When the spring is removed from the mandrel, it will expand to some extent, and if a spring of a definite inner diameter is required, it is necessary to experiment with several mandrels of slightly different diameters. Extension springs may be formed by winding the wire closely. Springs of conical or bulb shape may be wound by using special mandrels.

142. Fig. 11-41 illustrates a method of making a shaft with a tapered hole in one end, in which the axis of the hole and the axis of the shaft must be coincident. The stock is first centered at both ends and a seat for the application of steadyrest jaws turned on it. The shaft is then set up as shown in Fig. 11-41, one end being supported by the steadyrest and the other bearing on the live center. Rawhide belt lacing is employed to keep the work on the live center. The steadyrest jaws must of course be carefully adjusted to the turned seat so that the right end of the shaft is running true. (A dial indicator is generally employed to determine the concentricity of the turned seat and the spindle axis.) The hole is then drilled to the proper depth, and the taper hole bored by using a boring tool (similar to the tool of Fig. 11-27), with the compound rest set over at the proper angle. (If deemed necessary, the taper attachment could be used for this operation.) A turning plug with a taper portion fitting the bored hole is then made, and inserted in the shaft so that the outer diameter may be turned. After turning and facing, the taper plug is removed and the shaft is complete.

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FIG. 11-42. Facing the End of a Bar with a Right Hand Offset Turning Tool.

A similar operation is illustrated in Fig. 11-42. In this case the bar is clamped in an independent chuck, centered by drilling from the tailstock, and turned for a steadyrest seat while the end of the bar is supported by the dead center. The dead center is then removed, and a steadyrest applied to the turned seat so that the end hole may be drilled and bored. As the bar is not centered at the headstock end, it is more difficult to turn the entire

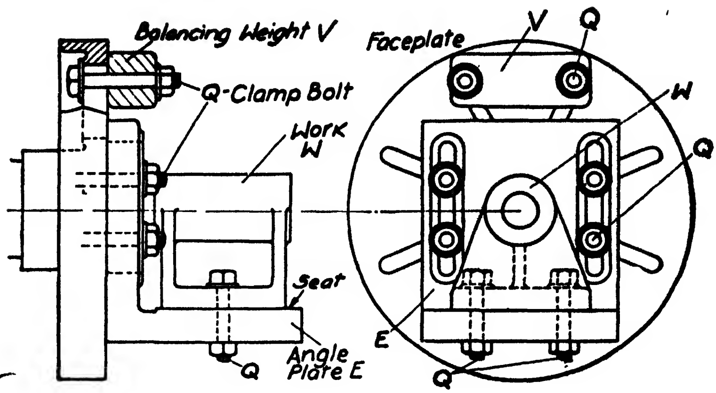

FIG. 11-43. Boring a Casting by Clamping It on an Angle Plate Clamped to the Faceplate of a Lathe.

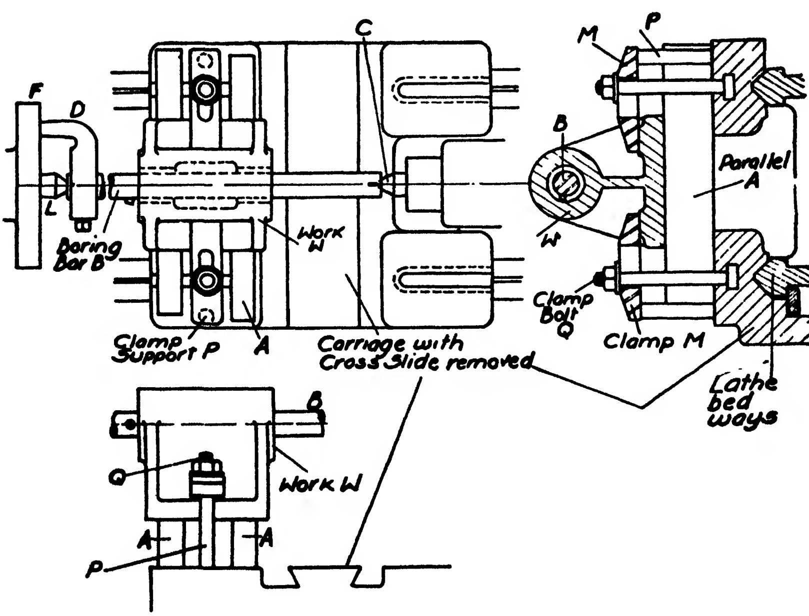

FIG. 11-44. Boring a Casting by Clamping It on the Carriage oɪ a Lathe, Using a Boring Bar between Centers.

length of the bar concentric with the hole. Heavier cuts can be taken, however, as the chuck jaws hold the work firmly.

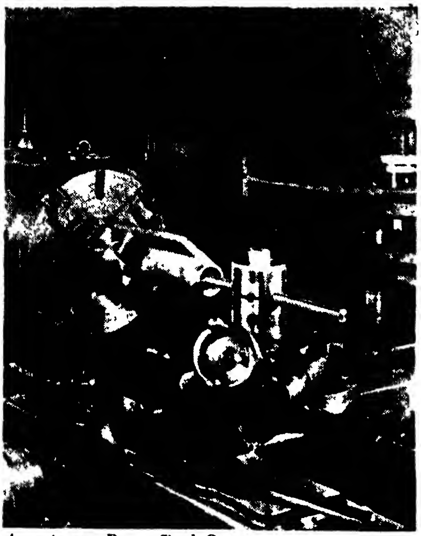

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FIG. 11-45. Boring a Casting Held in an Independent-jaw Chuck. The Three-bar Cutter Head Replaces the Tool Post Assembly. Wrench for Clamping Cutter Head Shown on Carriage.

143. In many shops the lathe is used for boring non-cylindrical castings. Fig. 11-43 shows an arrangement for boring the cylindrical hole in the frame of the burring machine illustrated in chapter 3. An angle plate *E* is clamped to the large faceplate of the lathe with the seat of the angle plate located at the correct distance from the centerline of the lathe spindle. The frame to be bored is then clamped to the angle plate. A balancing counterweight *V* is employed to balance approximately the overhung angle, and the work is bored by employing a single-point boring tool held in the tool post of the lathe.

Another method of boring this casting is shown in Fig. 11-44. In this instance the cross-slide of the lathe is removed, and the work supported on parallels resting on the upper (finished) surface of the carriage. Parallels of the proper size are of course employed so that the distance from the axis of the hole to the base will be correct after boring. A single-point boring bar, supported between centers and driven by a dog, is used to bore the hole as the carriage feeds to the right.

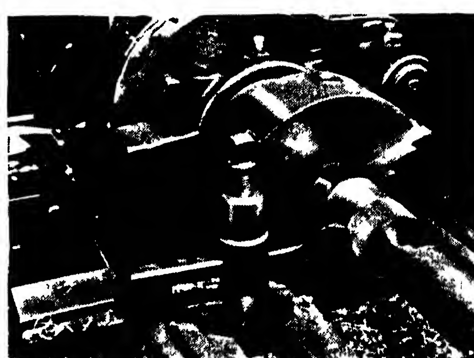

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FIG. 11-46. Knurling Tool. Knurling Work Which Is Subsequently Cut from the Bar with a Cut-off Tool.

Fig. 11-45 shows a casting held in a chuck while the hole is bored. In this case the flat base of the casting is machined after the hole is bored to insure parallelism of the axis of the bored hole and the base.

144. Knurling is the process of forming a series of fine ridges upon the periphery of a circular part such as a screw head or knob, to facilitate its rotation by hand, although knurling is often done for a purely ornamental effect. Knurling may consist of small, closely spaced ridges which are either at an angle to the axis of the surface of revolution or parallel with it like the milled edges of a coin. A knurling tool, illustrated in Fig. 11-46, generally has a pair of rolls with diagonal teeth inclining in opposite directions, which are pressed against the unhardened work and rotate with it, thus forming small diamond-shaped projections on the surface of the work. The rocking holder which carries the knurling wheels fits into a circular seat in the tool so that it is free to adjust itself, and so that both rolls bear on the surface of the work with equal intensity. Except for this, one of the rolls might bear more heavily than the other and thus produce an irregular pattern.

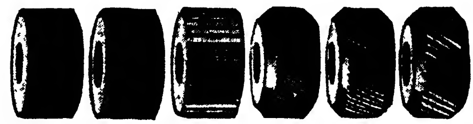

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FIG. 11-47. Knurling Rolls.

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FIG. 11-48. Knurled Surfaces.

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FIG. 11-49. Right Hand Offset Cutting-off Tool Used to Cut Discs from a Bar Held in a Chuck.

The work should be supported as rigidly as possible since knurling requires a considerable transverse pressure. For this reason, work which is to be knurled should be rough-turned, finish-turned at the region to be knurled, and then knurled. After the knurling operation has been completed, the remaining surfaces should be finished so as to compensate for any deformation caused by the knurling pressure.

145. It is often necessary to locate holes accurately in machine parts, and the method of laying out the centers of these holes, and then drilling by starting the drill at the centerpunch mark is not sufficiently precise, not only because of the limited accuracy of scaled and scribed lines but

also because the drill will rarely follow the centerpunch mark exactly. In such instances, where precision to .001" or even .0005" is required, one or

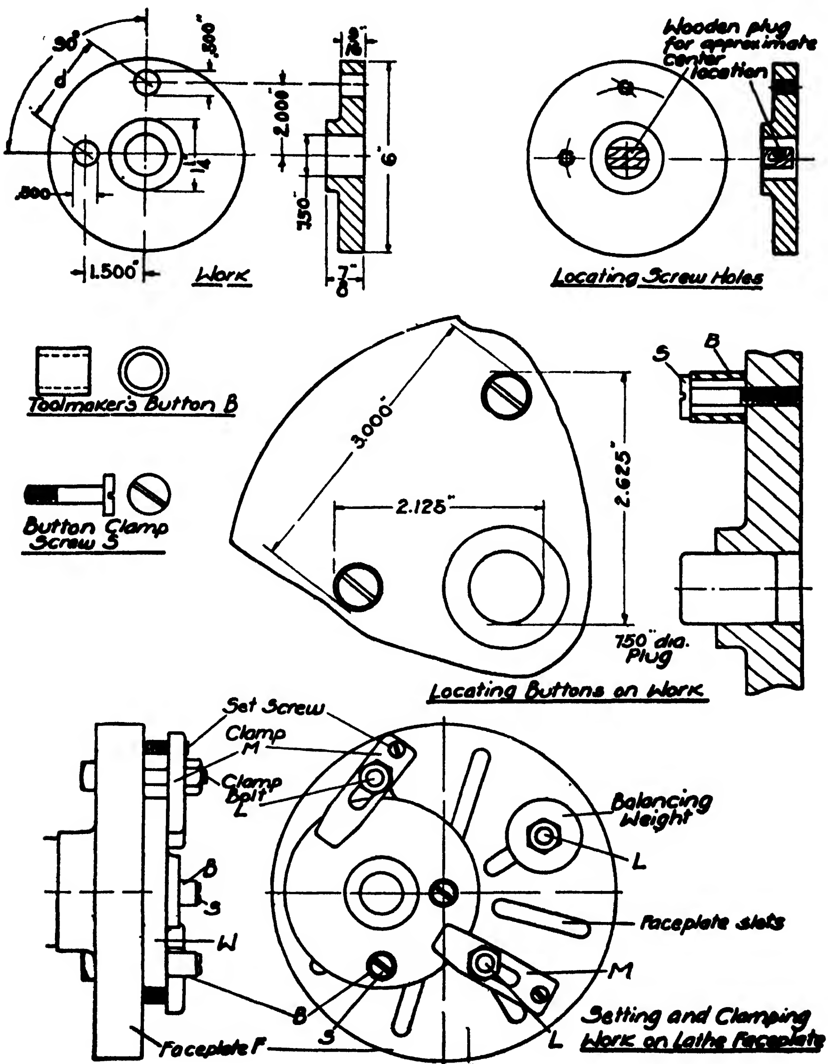

FIG. 11-50. Locating Holes Accurately by Using Toolmakers' Buttons.

the other of the methods illustrated in Figs. 11-50 and 11-51 is employed. Fig. 11-50 shows accurate hole location by the use of so-called **tool-**

makers' buttons which are hardened and ground hollow steel cylinders with squared ends. They are made in three sizes: .300″; .400″, and .500″ diameter, and are about ½″ high. They are obtainable in sets of four with screws S to correspond. The screw size is No. 10-32-N.F., with a

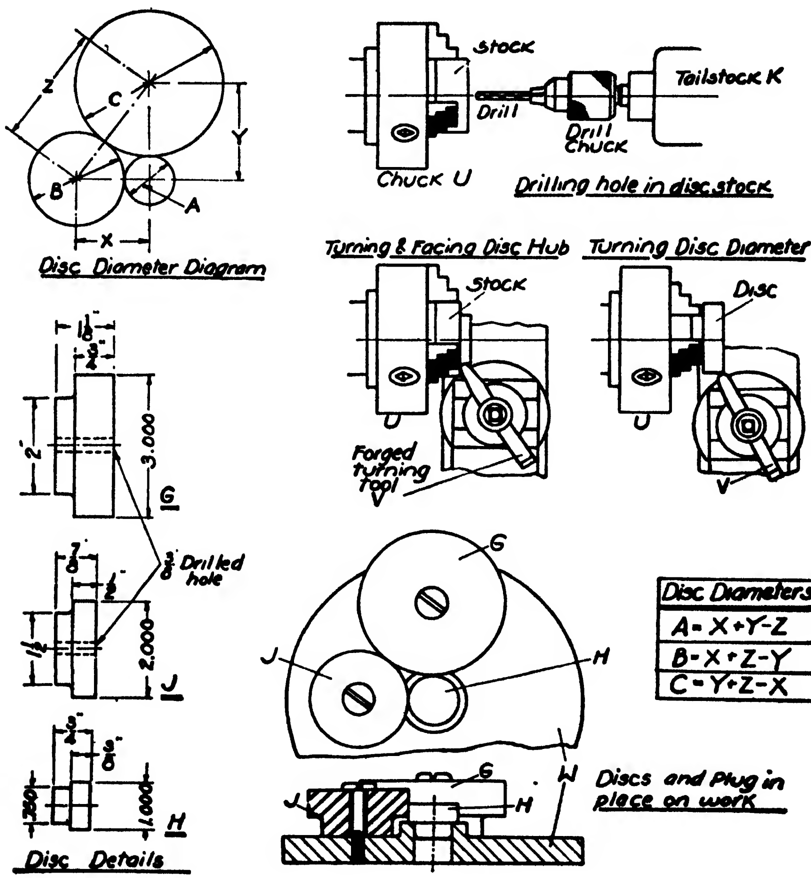

FIG. 11-51. Locating Holes Accurately by the disc method.

$\frac{7}{16}$″ head for the .500″ button. Fig. 11-50 shows a small plate which has been turned and completely finished except for the two .500″ holes, which are to be located as indicated by the dimensions. In the first operation, a wooden plug is driven into the central hole and employed as a support for one point of a pair of toolmakers' dividers. Two arcs, one of 1½″ radius, and the other of 2″ radius, are next scribed using the approximate center of

the .750″ hole, and a centerpunch mark is placed somewhere on the 1½″ arc. The distance *d* is next calculated (and is found to be 2.500″), and a 2½″ radius arc is scribed, intersecting the 2″ arc at which another centerpunch mark is placed. The two marks serve as the centers for No. 10-32-N.F. tapped holes which are drilled and tapped in the plate. In the next stage of the process, the two buttons are fastened to the plate by means of the screws, and a .750″ plug is pressed into the central hole. Next, the buttons are adjusted until the three dimensions shown are obtained. This can be done by screwing the screws down lightly, and then tapping the buttons with a lead or brass hammer to cause slight changes in their position. (The three dimensions measured over the buttons are obviously greater than the three center-to-center dimensions of the part, as the button diameter—.500″, and the plug diameter—.750″ must be accounted for.) When the buttons are correctly located, the screws are firmly fastened, the distances checked, and the plate strapped to a lathe faceplate and adjusted so that one of the buttons is concentric with the lathe spindle axis without changing the position of the button on the work. The button is then removed, and the threaded hole drilled out and bored to the .500″ diameter. When the first hole has been finished, the operation is repeated for the second hole. The distances are measured either with a vernier caliper or a micrometer, and it is usually necessary to use a dial gage to insure concentricity of the button with the lathe spindle axis when setting up the part on the faceplate. In the figure, two flat clamps are used, held by bolts passing through the lathe faceplate slots. A counterweight is generally bolted on the faceplate to approximately balance the offset weight of the plate.

The button method is accurate but is tedious and time-consuming. Another method of accurate hole location, employed where the distances between hole centers is not too great, is illustrated in Fig. 11-51, and is known as the **disc method.** In employing this method, the machinist or toolmaker determines the diameters of three discs, which if placed in tangency, will give the required center distances. He then turns up three such discs and attaches them to the work in a manner similar to the button method, except that as long as they are attached in tangency no adjusting or measuring is required. The work is then bolted to a lathe faceplate and the discs are successively aligned with the spindle and then removed to permit boring the hole.

The illustration shows the details of three such discs, one of which is pressed into the .750″ diameter hole in the work, while the other two are attached by screws similar to those in Fig. 11-50. The illustration also indicates the operations necessary to make a disc. (A universal chuck may be

employed because the central hole need not be absolutely concentric with the outer periphery.)

In setting the work on the lathe faceplate, disc G should be aligned first since it projects sufficiently past discs J and H to permit the point of the dial indicator to touch it over its entire periphery without interference.

The table on Fig. 11-51 gives the formulae for the disc diameters in terms of the center distances X, Y and Z.

CHAPTER 12

SINGLE-POINT TOOL MACHINING PROCESSES

146. Planers, shapers and slotters are machine tools that employ single-point tools to generate flat surfaces. In each of these the relative motion of the cutting tool and the work is rectilinear, and either the tool or the work feeds in a direction perpendicular to the cutting stroke. In the **planer,** the work is held on a horizontal table and moves past a stationary tool; in the **shaper,** the work is stationary and the tool moves over it. The **slotter** may be called a vertical shaper, since the tool moves in a vertical direction past the stationary work. All three machines finish surfaces in a similar manner, and their selection depends primarily upon the nature of the work.

The **planer** is generally used for large work. For comparatively small work the **shaper** is used, unless a large number of like parts are to be finished. In this case the parts are frequently placed on a planer table in rows, and a number of parts are planed at one setting. This operation is referred to as *string* planing. The **slotter** is used for machining flat surfaces which are difficult or inconvenient to machine because they are at right angles to the main dimensions of the part. The slotter is also employed for cutting internal keyways, square holes, and die openings.

Planers and shapers are used for machining surfaces to a high degree of accuracy, and in general require less power per cubic inch of metal removed than machine tools employing multi-toothed cutters. Planer and shaper tools are considerably less expensive than milling cutters; the planer may therefore be used in preference to a milling machine if the castings are poor and subject to hard spots.

147. A modern **industrial shaper** is shown in Fig. 12-1. The ram operating mechanism is illustrated in Fig. 12-2. The lever arm operates about a fixed fulcrum F, and is driven by crank pin P and block X. The length of the ram stroke may be changed by increasing or decreasing the radius D of the crank pin P. This is done by turning the crank pin position screw W by means of bevel gears operated from the exterior of the shaper. The mechanism is so designed that the greater portion of the rotative cycle of the crank, illustrated by A and by B, is employed for the cutting or forward stroke. The link L connects the lever arm and the positioning nut N. The position of the ram and cutting tool with respect to the work is altered

by turning S by means of bevel gearing and shaft H. The ram is locked with respect to the lever arm by clamp lever C.

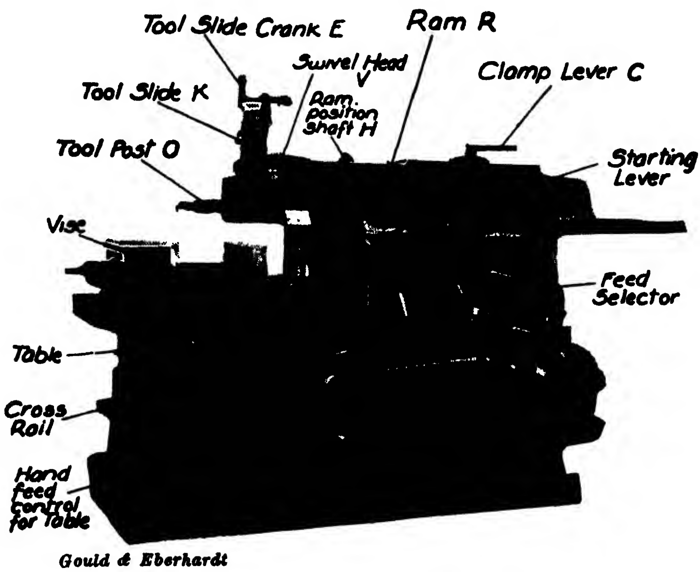

FIG. 12-1. 28" Industrial Shaper.

The ram carries the tool slide K, which in turn carries a tool post O on a clapper block, permitting the tool to lift on the return stroke as illustrated.

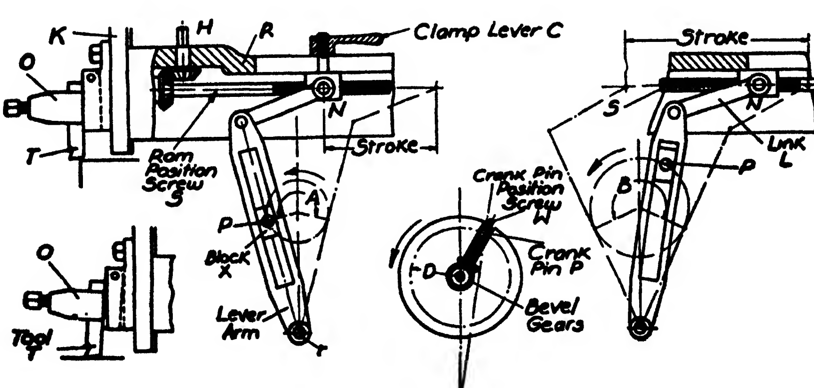

FIG. 12-2. Principles of Shaper Operation.

As the ram returns, the table feeds across the cross-rail for the next cut. Vertical feeding, or feeding at some angle to the horizontal, may be obtained

by a power feed mechanism applied to the tool slide. Two examples of such operations are indicated in Figs. 12-3 and 12-4. In Fig. 12-3 the operation shown is that of cutting body grooves for tee-slots, and a vertical feed of the tool slide is employed. In Fig. 12-4, the tool slide is set at an angle so that the dovetail slide illustrated may be machined. The figure shows the right side of the finished dovetail, and the left side partially machined. Fig. 12-5 illustrates the stages in tee-slot cutting. The first illustration shows the body groove half finished; the next shows the completed groove. Both figures illustrate the use of the vertical or down feed. The next three illustrations show the successive operations on the tee of the tee-slot, where the horizontal table feed is employed, first to the right, and then to the left.

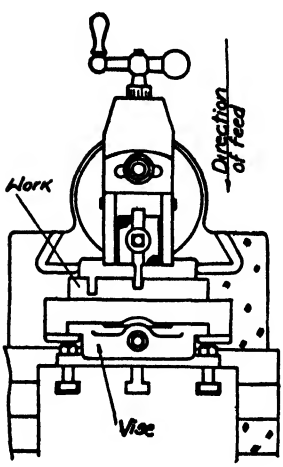

FIG. 12-3. Planing Body Grooves for Tee-Slots.

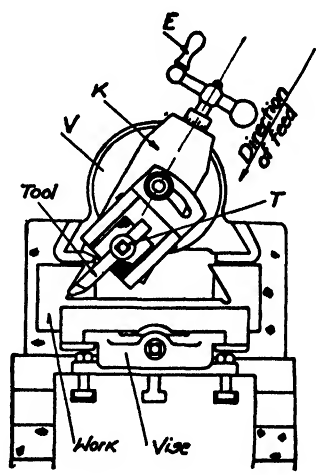

FIG. 12-4. Planing Dovetail Slides.

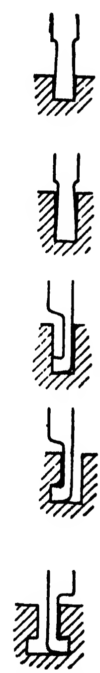

FIG. 12-5. Stages in Cutting a Tee-slot on a Shaper.

148. Shaper and planer tools are similar to solid or inserted-bit lathe tools. An adjustable head tool designed to permit setting of inserted tool bits at any angle to the tool shank is shown in Fig. 12-6. Extension tools shown in Figs. 12-8 and 12-9 are used for cutting keyways and square and splined holes.

Shaper work may be held in a vise or clamped to the shaper table. The vise is employed wherever possible, since the work may be set up and clamped more easily and quickly than by the other methods. In some instances, a vise may be used for large work if auxiliary supports, such as the supporting jacks or braces are used. Both single screw and double

screw vises illustrated in Figs. 12-7 and 12-6 are used for shaper and planer work. The single screw vise offers somewhat faster operation, but the double screw vise is more powerful and makes it possible to clamp taper pieces without the use of extra jaws or shims.

In the shaper shown in Fig. 12-1, the table moves in a horizontal plane, although its height may be adjusted by raising or lowering the cross-rail.

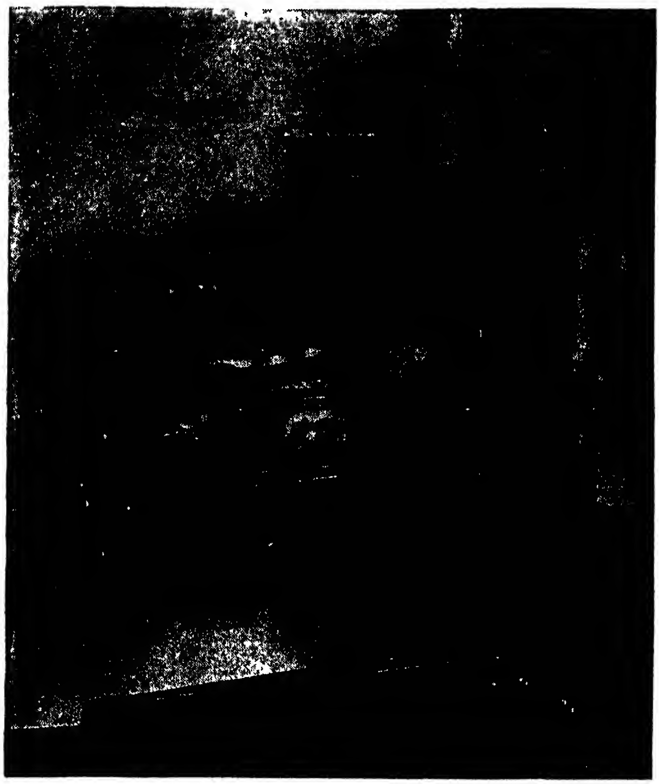

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FIG. 12-6. Shaper with Universal Table.

Fig. 12-6 illustrates a **shaper** with a **universal table** which has one solid face and one tilting face with adjustment up to 15° either way on an axis at right angles to the trunnion. The table itself may be set at any angle about the trunnion axis which is parallel to the motion of the ram. By using the swivelling vise illustrated in Fig. 12-8, work can be rotated and adjusted around all three axes.

149. Fig. 12-9 illustrates a **special fixture** used to hold collars while keyways are cut by the use of a shaper extension tool *Y*. The work is seated

in a vee-block that is part of the fixture, and clamped in place by a collar screw. The fixture is bolted to the shaper table by a tee-bolt, and kept in alignment by two keys fitting in the tee-slots. The ram is set in such a position that the work may be easily removed, and the vertical feed of the tool slide is employed to obtain the depth of the keyway. This operation could be performed by holding the work in a vise, as in Fig. 12-8, but the use of the inexpensive fixture facilitates setting and holding the collar. The rear of the fixture wall has a hole through which the tool shank can pass at the end of the stroke.

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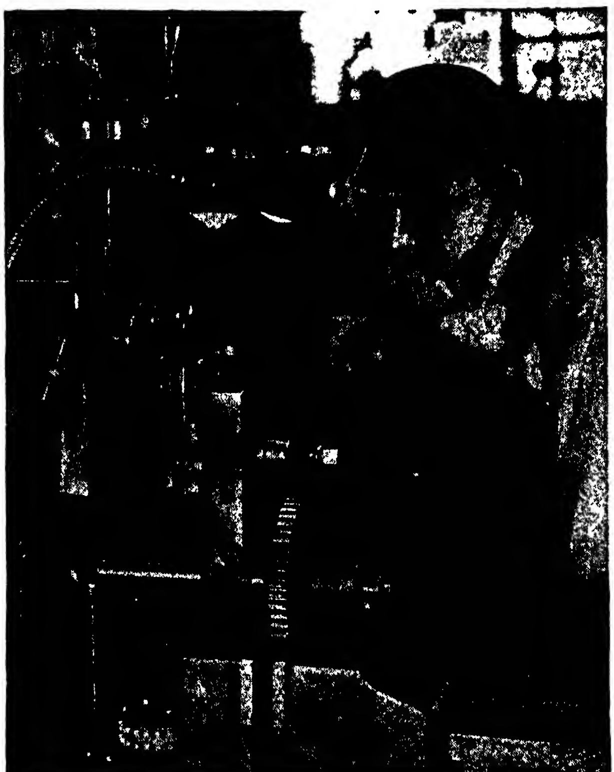
FIG. 12-7. Machining an Airplane Fuselage Die on a Universal Shaper.

Shapers may be employed for a great variety of plane surface work; for special shapes which are obtained by hand-operating the cross-feeds and the down-feeds, as shown in Fig. 12-7, and for shaping segments of circles, which may be handled by rotating the swivel head while the table is stationary.

150. Hydraulically-actuated machine tools are coming into extensive use in the metal-working industry. Fig. 12-10 shows the principles of operation of a **hydraulic shaper.** The ram receives its reciprocating motion from a piston which is moved forward and backward by a flow of oil from an electrically-driven variable-delivery pump. The piston speed is changed by varying the amount of liquid delivered by the pump. The illustration shows a diagrammatic representation of the valve position while the ram is moving to the left on its cutting stroke. The oil from the pump flows through port *B* in the valve, through discharge line *E* to the cylinder, moving the piston to the left. When the ram reaches the end of its stroke, a dog or trip moves the valve to the right so that ports *A* and *B* are in alignment with lines *D* and *S*. The oil from the pump then flows to the cylinder through port *A* and line *D*, moving the piston to the right. The oil in the head end of the cylinder returns through line *S* and port *B* to the oil reservoir.

Hydraulically-actuated machine tools offer great flexibility of speed and feed control, elimination of shock, and possess the ability to *stall* against obstruction, thus protecting parts or tools from breakage. Hydraulic actuation also permits *slip,* or slowing-up of motion, when the cutting tool is overloaded. If a hydraulic drive were used to actuate the



Armstrong Bros. Tool Co.

Fig. 12-8. Cutting an Internal Keyway in a Sprocket.

carriage of a lathe, accurate thread cutting would not be possible because the slip would not be compensated for at the end of the movement. In mechanically-actuated feeding mechanisms, any slip that may result from slight deformations of the mechanism must be made up, and may therefore result in an increased rate of motion during some portion of the total movement.

Another form of hydraulic circuit employs a constant-delivery pump which may move the piston at a rate corresponding to only a fraction of

the displacement of the pump. The excess displacement escapes through a relief valve in the feed line into the oil reservoir. The rate of motion of the piston is therefore controlled by the setting of the relief valve.

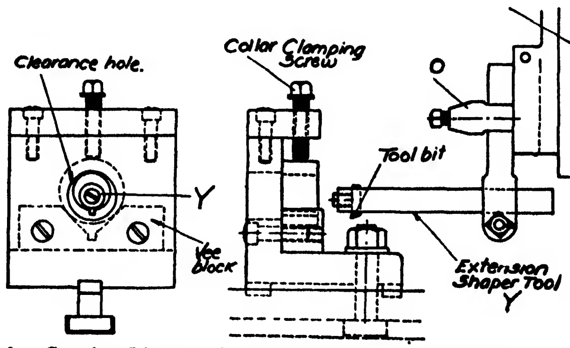


FIG. 12-9. Special Fixture for Cutting Internal Keyways on a Shaper.

Hydraulic circuits for intermittent or varying rates of feed and for rapid traversing motions in combination with feeding motion are in extensive use on various types of machine tools. Two or more cylinders,

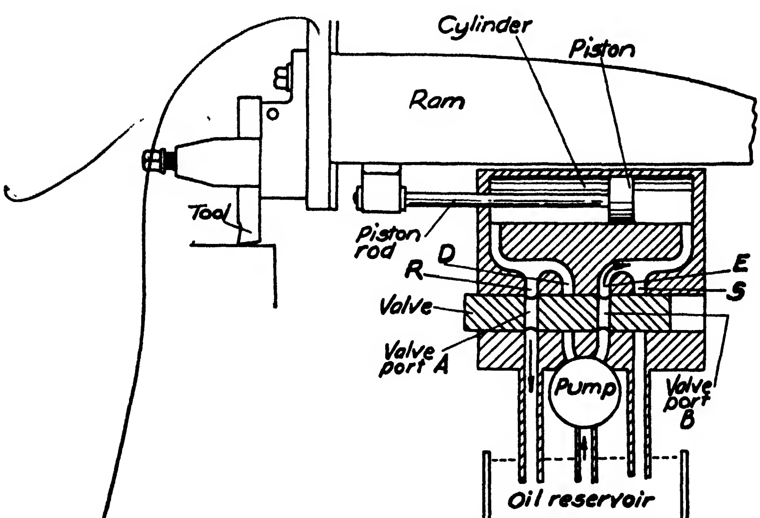
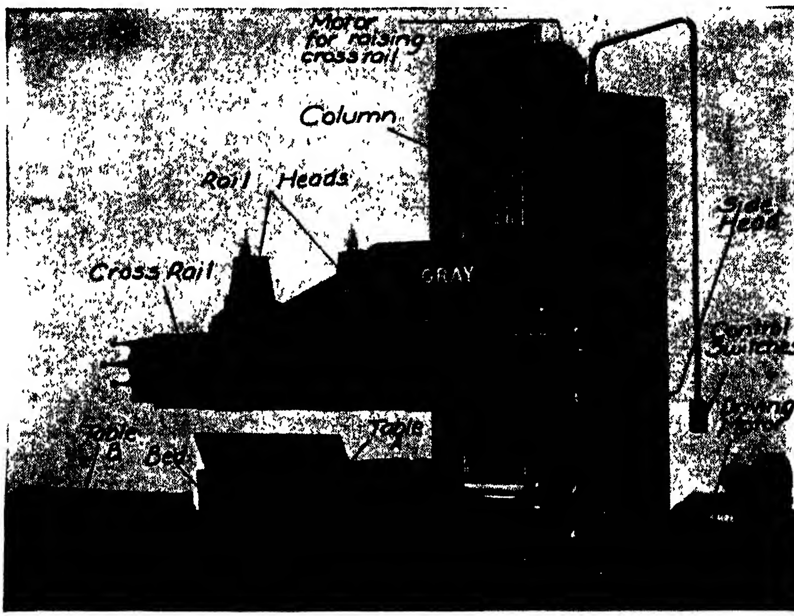


FIG. 12-10. Principles of Hydraulic Drive for Shaper.

with varying rates of motion, may be driven from the same pump by proper application of valves and control equipment. Rotary motion may be obtained by using a rotary hydraulic motor instead of a feed cylinder.

151. There are two standard types of **planers** that are in extensive use in jobbing and production shops. One of these types is the **double-housing planer;** the other is the **open-side planer** illustrated in Fig. 12-11. The work is bolted or otherwise securely fastened to a table or platen, the under side of which is provided with two accurately machined guides which slide in guide ways on the planer bed. The table moves against one or more cutting tools, which are held by the rail and side heads,



G. A. Gray Co.

FIG. 12-11. Open-side Planer with Duplex Table.

at a speed adapted to the material to be cut. The return stroke, during which no cutting takes place, is usually constant, but is from two to four times as fast as the cutting stroke so as to economize time.

The cross-rail is mounted on a vertical column and may be elevated or lowered to accommodate various classes of work. In principle, the rail heads are like shaper heads, and can be adjusted to any convenient position along the cross-rail. Small planers are generally equipped with only one rail head, but larger machines have two rail heads and an independent side head, which, by feeding vertically on the column, can be used for machining the sides of the work while the top is being machined. The tool feed is obtained by moving the rail heads on the cross-rail and the side head on the column and may be manually or mechanically actuated. In

the planer illustrated in Fig. 12-11, power-actuated traversing as well as feeding motions are available.

Three methods are employed for driving planer tables. In the first method, a helical rack on the underside of the table is driven by a helical *bull* gear, which is in turn driven by a pinion and one or more additional trains of gearing. In the second method, the rack on the underside of the table is driven by a worm whose shaft is at an angle to the centerline of the table. The third method of driving a planer table is similar to the hydraulic shaper drive previously discussed.

If the planer table is mechanically driven, the direction of rotation of the driving gears must be reversed at the end of the table movement. Fig. 12-12 illustrates a **belt-driven planer** which receives its primary power input from a uni-directional motor at the top of the column. The motor drives the countershaft *C* by a sheave *S* and vee-belts. The driving shaft of the planer is driven by two belts, *X* and *Q*, running on pulleys *B* and *E*. Each of these pulleys is a tight-and-loose set so that, when the belt *X* is on the tight element of pulley *B*, the belt *Q* will be on the loose element of *E* and vice-versa. The belts are shifted by a mechanism controlled by trip dogs on the planer bed.

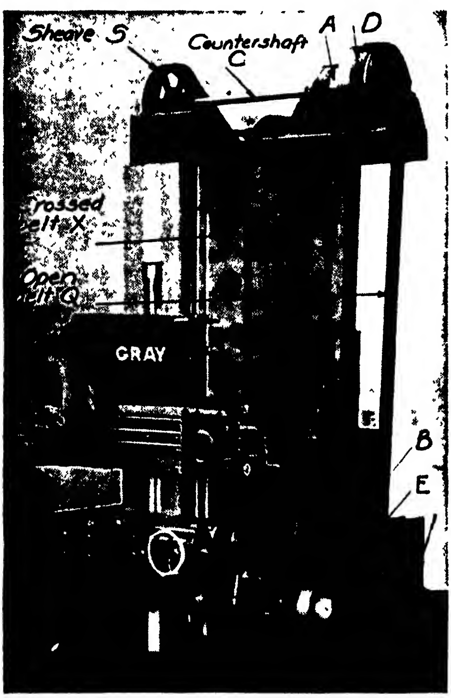


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FIG. 12-12. Belt-driven Openside Planer.

Most of the modern planers, however, use a **reversing motor drive** instead of the belt shifting arrangement. Reversing motor drives require less attention and maintenance than belt drives, and will reverse more quickly, particularly on large machines.

152. Double housing planers have a column or housing at each side of the planer bed. The housings are tied together at the top by a top brace or arch. The cross-rail is supported on the faces of both housings. In the large sizes, there is often a side head on each housing, so that four tools may operate at one time.

Planer size is determined by the maximum stroke of the table and the width and height of work that will pass through the housings and underneath the cross-rail. A double housing 30″ × 30″ × 8′ planer, for instance, will machine a part 30″ high, 30″ wide and 8′ long. Openside planers are classified by the cross-rail height and the length of stroke, and will generally handle work that is somewhat wider than its height.

In modern high-speed planers, the actual cutting time has been reduced so much that the time expended in setting up and clamping the work becomes

Erie Foundry Co.

FIG. 12-13. Machining the Upper Surface of a "Sow" Block for a Drop Hammer on a Double-Housing Planer, Using a Forged Tool.

increasingly important. The planer illustrated in Fig. 12-11 has **duplex tables,** so that a job can be set up on one table A while a part on the other table B is being machined. Facilities are provided for quickly bringing the second table to cutting position. With this arrangement, the amount of time required for a job is either the set-up or the machining time, whichever is the larger. For long work, the duplex tables may be joined and used as one table.

Planer work may be held in a vise bolted to the planer table or the work may be clamped directly to the table. The table has three or more

tee-slots running lengthwise and numerous holes for inserting stops and clamping blocks. Castings can generally be clamped in place by using straps or clamps on projecting portions of the work. Fig. 12-14 illustrates two methods of holding down comparatively thin work where it is impracticable to seat a clamp on the upper surface.

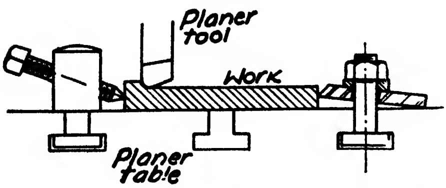


FIG. 12-14. Two Methods of Holding Thin Work on a Planer Table.

Planer tools are similar to lathe and shaper tools, but are somewhat larger. Fig. 12-15 shows a tool holder with an inserted bit, in which the bit may be set at various angles to the shank so that angular and other surfaces may be machined without shifting the position of the work on the table. Fig. 12-16 shows a **gang planer tool** which is especially adapted for surfacing large castings. As each chip is comparatively light, a planer will, with this tool, carry a feed and depth of cut much greater than is possible with a single-tool point. With a gang tool there is also less tendency to *break out* at the end of the cut. The tool illustrated has a fixed feed ratio, but swivel head tools, which may be set for any desired feed, are also available.

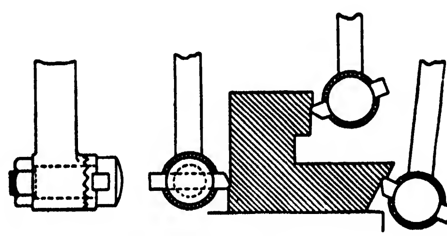


FIG. 12-15. Adjustable Head Planer Tool.

153. A motor-driven **slotter** or **vertical shaper** is illustrated in Fig, 12-17. The ram reciprocates in a ram slide which may be swung to any angle from a vertical position up to 5° from the vertical. The ram receives its reciprocating motion from a rotating crank which drives a slotted rocker arm through a driving block.

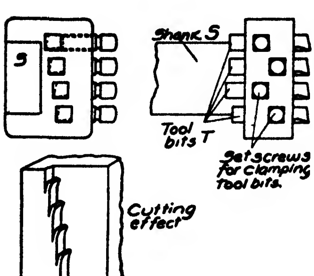


FIG. 12-16. Gang Planer Tool.

A movable saddle is mounted on the bed and dovetail guides permit motion in one direction. The table base is mounted on the saddle and guides integral with the saddle permit perpendicular transverse motion. The rotary table is mounted on a swivel bearing in the table base and may be rotated about its center. The rotary table may be rotated for feeding in either direction by power or by the use of the handwheel; and both the table base and the saddle may be hand-adjusted or

power fed in either direction. The rotary table has a graduated edge, and the table handwheel has a micrometer dial subdivided so that the smallest divisions represent two minutes of arc. There are indexing notches provided so that the table can be indexed quickly through the major angles and positioned exactly by a small plunger.

Pratt & Whitney

FIG. 12-17. Vertical Shaper.

Fig. 12-18 shows a machine part clamped to the rotary table of a vertical shaper with the cylindrical hole in the part centered about the table axis. The part is located against a parallel seated against two blocks in the left tee-slot, and is held down by two clamp straps. The sides of each slot in the work are finished by feeding the saddle towards the rear of the machine. The end of each slot is finished by feeding the table transversely. The rotary table is hand indexed for each slot.

Pratt & Whitney

FIG. 12-18. Machining Four Slots and Outside Bosses on a Vertical Shaper.

Fig. 12-19 shows the necessary operations for slotting a rectangular through hole in a machine part by using a tool and a set-up similar to that of Fig. 12-18. Stage *A* shows the part fastened to the slotter table, with

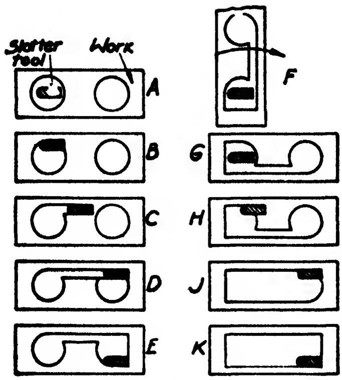


Fig. 12-19. Sequence of Operations in Machining a Rectangular Slot on the Vertical Shaper.

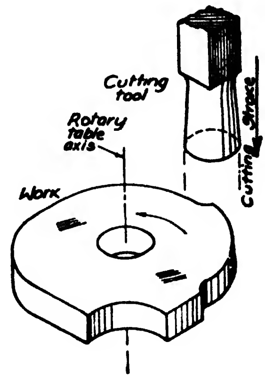


Fig. 12-20. Cutting a Cam on a Vertical Shaper.

two holes drilled in it and the slotting tool *T* in place. In stage *B*, the work *W* moves to the left; in stages *C* and *D* the work moves to the rear of the machine; and in *E* the work moves to the right. Stage *F* shows the rotary table turned 180° to relocate the part so that the other edges may be finished, which is accomplished in stages *G, H, J,* and *K*. (The cutting edge of the slotting tool is towards the front of the machine.)

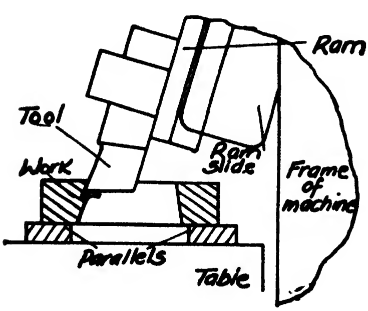


Fig. 12-21. Machining Dies on the Slotter.

Fig. 12-20 illustrates a cam cutting operation on the slotter. The tool is circular and has a diameter equal to the diameter of the cam roller. Cylindrical surfaces that are concentric with the cam shaft axis are machined by employing the rotary feed of the table; other surfaces are finished by combined operation of the transverse and longitudinal feeds.

Fig. 12-21 shows the ram slide set to cut at an angle with the vertical. This adjustment is used primarily for die machining so that the necessary relief in a die may be obtained while the contour of the die is finished. The ram slide adjustment is limited to a maximum of 5° from the vertical, but is exaggerated in Fig. 12-21 for clarity.

154. **A boring mill** is essentially a lathe set on end. The machine illustrated in Fig. 12-22 has a rotating horizontal table which is driven by a vertical spindle. The single-point cutting tools are carried in tool heads

Consolidated Machine Tool Corp. of America

Fig. 12-22. Turning a Car Wheel Tire on a Boring Mill.

on rams that may be adjusted and fed vertically, and may be positioned or fed along a supporting cross-rail. The cross-rail may be positioned vertically on two housings. The ram carrying the tool head can usually be

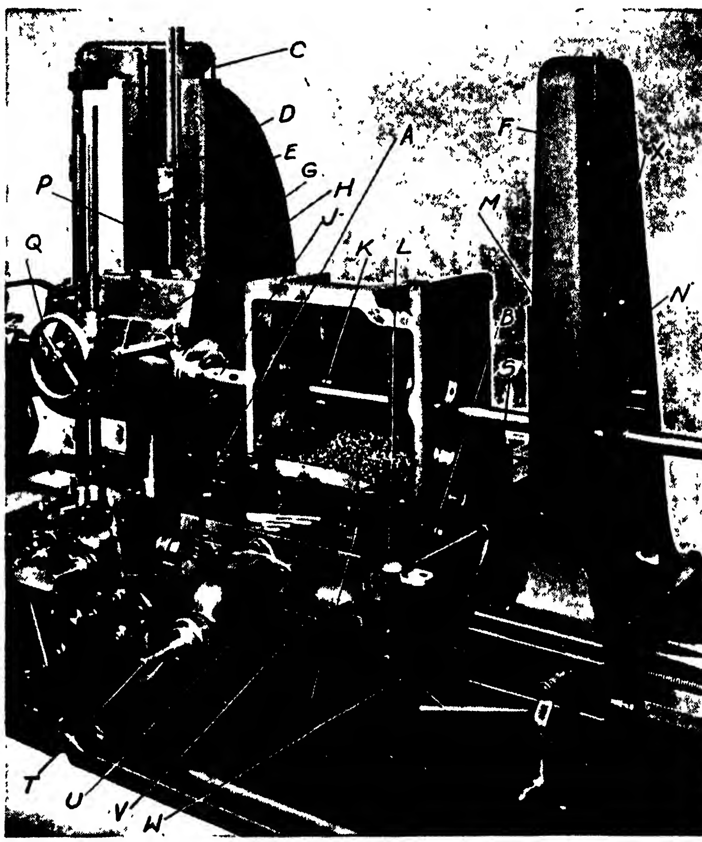
Consolidated Machine Tool Corp. of America

Fig. 12-23. Facing a Large Casting on a Vertical Boring Mill.

set at an angle to the vertical for boring taper holes and machining external taper surfaces.

The **vertical boring mill** is used for turning and facing operations in which it is more economical or feasible to mount the work on a horizontal

table, than to bolt or clamp the part to a lathe faceplate. The machine is also used instead of a planer for surfacing the ends of cylindrical castings as illustrated in Fig. 12-23. This casting has a large central hole and a comparatively narrow annular rim. If the rim were finished on a planer, the tool would be cutting during only a small portion of the tool stroke



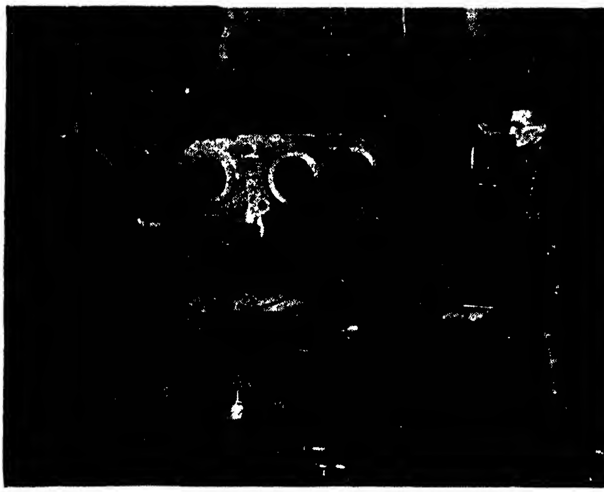
Lucas Machine Tool Co.

Fig. 12-24. Horizontal Spindle Boring Machine.

required; the boring mill employs a radial feed and is constantly cutting if the rim is concentric with the table axis.

155. There are two important types of **boring machines:** those with a horizontal spindle, and those with a vertical spindle. **Horizontal spindle boring machines** for large work are built with a base or floor plate level with the floor of the shop. **Table-type horizontal spindle boring machines** have a table *U* which is mounted on a saddle *V* as illus-

trated in Fig. 12-24. Both the table and the saddle are equipped with power feed and rapid traverse movements; the table *on* the saddle, in a direction perpendicular to the spindle *J;* and the saddle parallel to *J, on* the bed *W.* The spindle rotates in the spindle head *H* which may be power adjusted or fed along the vertical face of the column *G* by rotating the screw *P.* The boring bar *S,* which carries a cutter *K,* is similar to bar No. 1, Fig. 10-44. The bar fits into a standard taper socket in the spindle, and is supported at its right end by a bearing *M* in a block *X* in the back-rest *F.* The block may be moved by a screw which is geared to screw *P* so that the bearing will move up or down with the spindle head, and thereby insure



Erie Foundry Co.

FIG. 12-25. Boring the Bearing Holes of a Board Drop Hammer Head.

the constant coincidence of the spindle and bearing block axes. The block is rigidly held by a clamp operated by lever *N.* The back-rest *F* may be set to accommodate boring bars of any length by moving it along the bed with the crank *Y,* and then locking it with clamp *Z.*

Boring, drilling and milling operations may be performed on boring machines. ~~Milling cutters~~ may be held in the spindle socket, or bolted directly to the large flange. Boring is handled with piloted bars whenever possible, but boring tools may be held in an adjustable boring head. Fig. 12-26 shows a head designed for use with the boring tool of Fig. 12-27 or with an inserted-bit straight shank boring tool similar to bar No. 3, Fig. 10-44.

The boring operations illustrated in Fig. 10-58 may be more easily performed, particularly in repetitive work, on the horizontal spindle boring

machine. The work is placed on the table and clamped, and either core-drilled and bored or rough and finish bored. When a number of parts are to be bored, the operator often clamps a parallel to the machine table to serve as a stop against which one edge of the base of the work may be located. The distance from the axis of the hole to the base may be accurately obtained by measuring the distance from the under side of the bar to the table. If a very accurate measurement is required, it may be necessary to bore the hole .010" undersize, remove the bar, insert a plug, and measure the distance between the underside of the plug and the table. Any necessary adjustment for height may then be made with the assurance that enough material remains in the hole for the final truing operations.

Fig. 12-24 shows a machine boring its own speed change gear box for anti-friction bearing mounting. The work is placed against stops *B* bolted

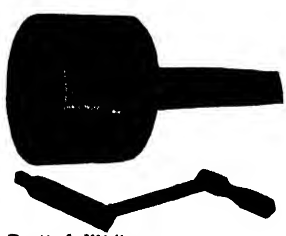


FIG. 12-26. Adjustable Boring Head and Crank.

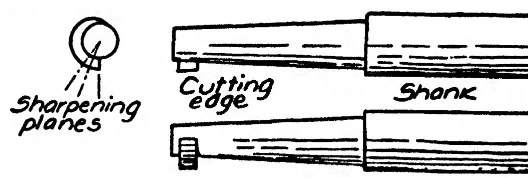


FIG. 12-27. Single-point Boring Tool with Straight Shank.

to the edge of the table, and held in place by clamps which are supported by step blocks *A* and held by tee-bolts. In boring the holes, it is necessary to locate each hole with respect to the others, which may be done by moving the table backward or forward and the spindle head up or down, by means of adjusting screws equipped with micrometer dials reading to .001". The spindle feed hand wheel *Q* is also equipped with a micrometer dial for accurate axial motion of the spindle so as to facilitate accurate facing and counterboring to depth.

156. For **very accurate hole location** in boring, the machine is provided with an auxiliary measuring device so that the adjusting screws are used only to bring the table and head into position. The machine has two dial indicators, *D* and *L*, graduated to read in half-thousandths of an inch, in holders adjustable on strips along the column and the side of the table. There are fixed abutments on the head and the saddle, with troughs to receive end measuring rods or inside micrometers. The measurement of the head or table movement is obtained by placing these end measuring rods or inside micrometers between the dial indicator points and the fixed abutments. The dial indicators are used to insure uniform measuring con-

tact. To illustrate the use of this equipment, suppose the next hole to be bored in the work shown in Fig. 12-24 is to be 1″ above and 2″ in front of the hole in process. After this hole is finished, a 4″ measuring rod *E* is placed against the abutment on the head, the dial indicator *D* is moved into position against the end of *E* and clamped, and the reading of the dial is taken. The 4″ rod is removed, and a 3″ rod with its end against the indicator, is substituted. The head is then elevated until the abutment touches the end of the 3″ rod. If this dial indicator reading is like the previous reading, it is evident that the head has been elevated exactly 1″. Measuring rods of any convenient length can of course be employed for these measurements, as long as they differ in length by 1″. In a similar manner, the table may be set back 2″ for the correct horizontal distance by using 5″ and 3″ rods between the dial indicator on the table and the abutment on the saddle.

Pratt & Whitney

Fig. 12-28. Vertical Spindle Boring Machine, or Jig Borer.

157. Fig. 12-28 shows a **vertical spindle boring machine** or jig borer. It is widely used for boring holes in jigs, fixtures, and dies, and has almost entirely replaced toolmakers' buttons or discs for accurate hole location. The machine has a horizontal table which may be moved from left to right on a saddle, which moves from front to back on the machine bed. Both the saddle and the table may be positioned by lead screws which rotate in fixed nuts. Two handwheels, one for rapid positioning and the other for slow motion precise positioning, are provided for each screw.

The table position is determined by using end measuring rods and a special inside micrometer between a fixed stop on the table and a dial indicator on the saddle. The saddle may be similarly positioned by measuring between a stop on the bed and a dial indicator on the saddle as illustrated in Fig. 12-29. The dial indicators are used as pressure gages to maintain a zero point and a constant measuring pressure.

The spindle rotates in a quill or sleeve which may move axially in the spindle head. The spindle may be hand or power fed and is driven from

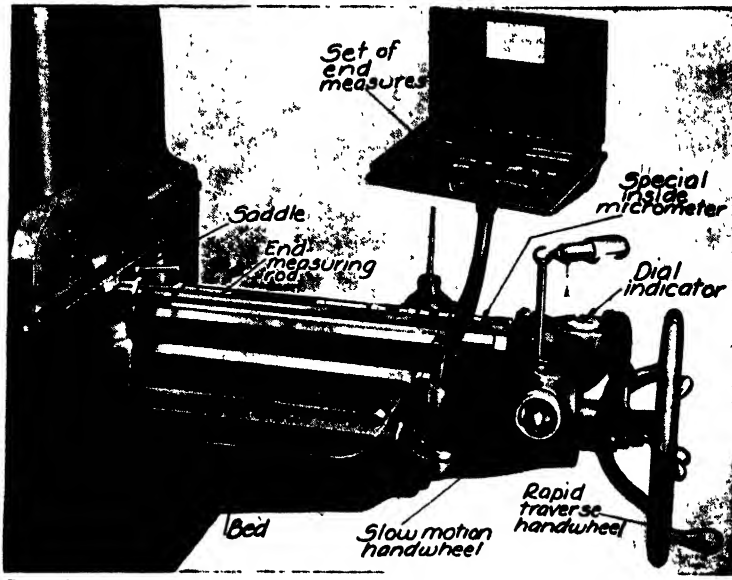


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FIG. 12-29. Locating the Position of the Table of a Jig Borer.

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FIG. 12-30. Gaging the Diameter of a Bored Hole.

G. A. Gray Co.

FIG. 12-31. Milling the Surface of a Base on a Milling Planer.

the motor at the back of the machine. The spindle nose has a taper hole to fit the shank of the boring head shown in Fig. 12-26, or to fit drills and reamers. Fig. 12-30 illustrates the operation of gaging the diameter of a bored hole. The cylindrical gage used is known as a stub gage, and is more convenient to use than the usual full length type because the spindle does not have to be elevated quite as much.

A rotary indexing table which may be tilted to bore holes in surfaces at various angles is also available.

158. In **precision boring,** the hole must be put where the measuring devices previously described have located it. Except for very small holes, the only method of securing quarter-thousandth accuracy consistently is to finish the hole with a single point boring tool. The hole is generally rough drilled undersize and finish bored. When the allowable tolerance is between .0005" and .0010", the hole may be spotted with an accurate spotting tool, rough-drilled undersize, and reamed with an undersize end mill. The end mill acts as a multiple-point boring tool and has sufficient rigidity to correct most of the drilling error. The hole is then finished with a sizing reamer. This method is much faster than the single-point tool method and is satisfactory for the given limits. When tolerances of several thousandths are permissible, the hole may be spotted, rough-drilled, and then reamed to size. This method does not require more than an average of a few minutes per hole.

159. A **milling planer** is similar to an open-side planer, but has a cross-rail that carries a planer tool head and a milling cutter head. The column carries a combination head which may be used for planing, milling and boring operations; this head is equipped with a spindle for carrying a boring tool or a milling cutter, as well as with the usual planer tool holder. Each head of the machine is an individual unit with an individual motor drive. The milling planer is particularly adapted to large heavy work since only one set-up is required for a wide variety of operations. Fig. 12-31 shows one of the many operations that can be performed on this machine. The part shown is planed, milled, drilled and bored at one setting of the work on the table.

CHAPTER 13

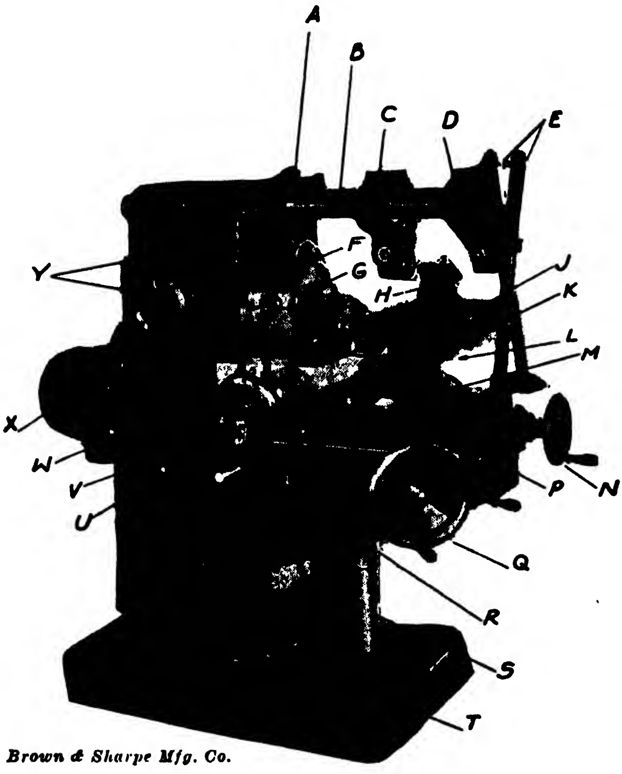
MILLING PROCESSES

160. Milling is the process of removing metal by multi-toothed rotating cutters. Milling machines may be roughly classified into four groups: column and knee type, bed type, planer type, and rotary type. Of these, the column and knee type machine is the only one that is extensively used in unit-production processes. There are other machines, however, that perform distinct milling operations, but because of their special character are not usually considered milling machines.

161. Column and knee type milling machines are made in three styles: universal, plain, and vertical spindle. They are used for both toolroom and manufacturing work because of their adaptability and because of the ease with which they may be handled. Fig. 13-1 shows a modern motor driven or constant-speed **universal milling machine.** The machine has a horizontal spindle *F* rotating in anti-friction bearings in the column *V*. The table *J* is mounted on and slides in dovetail guides on the saddle *L*. The saddle is mounted and swivelled on clamp bed *P*, which slides in dovetail guides on the knee *R*. *R* is free to move up and down on the face of the column *V*, and is supported by a screw within the telescoping cover *S*. In operation, the milling cutters are either attached to the spindle nose *F* or carried on an arbor or shaft which is driven from *F*. The work is held on the horizontal surface of the table. The table may be moved by hand by turning the crank *U* or by *rimming* the hand wheel to which *U* is attached. (Rimming is resorted to when a minute adjustment is to be made, and is illustrated in Fig. 13-23.) In the position shown in Fig. 13-1, the table can move in a direction perpendicular to the spindle axis. The saddle can be swung around at an angle, however, by swivelling on the clamp bed *P*, and the table can therefore be moved at angles other than 90° to the spindle axis. The saddle is provided with a graduated rim for angular settings.

The clamp bed *P* may be moved in a direction parallel to the spindle axis on knee *R* by turning the handwheel *N*. The knee may be raised or lowered by turning handwheel *Q*. All three elements: table, clamp bed, and knee, may be either power or hand fed by screws turning in fixed nuts. It may be seen, therefore, that the table can move in three planes and swivel in a horizontal plane.

162. Fig. 13-2 illustrates the principles of operation of a **milling machine feed transmission** system. The power feed is transmitted from the feed gear box (which is equipped with change gears and necessary shifting levers to provide feed changes) to shaft K in the knee by a telescoping shaft drive B and two universal joints V. (This type of drive is necessary on account of the vertical motion of the knee.) Gear G, which is integral with jaw clutch X, is keyed to shaft K and drives gear F, which



Brown & Sharpe Mfg. Co.

FIG. 13-1. Universal Milling Machine.

also has a jaw clutch attached but is free to rotate on the extension of the cross-feed screw H. Bevel pinion Z is free to rotate on shaft K and has a jaw clutch attached. Z is in mesh with bevel gear L which is fastened to the elevating screw P. Q serves as a nut for P, and as a screw in nut R which is fastened to a hub on the machine bed. P and Q serve as a telescoping screw combination and afford a vertical movement of the knee that is equal to the combined lengths of P and Q. (Another bevel pinion which is not shown in Fig. 13-2 is in mesh with bevel gear L and is attached

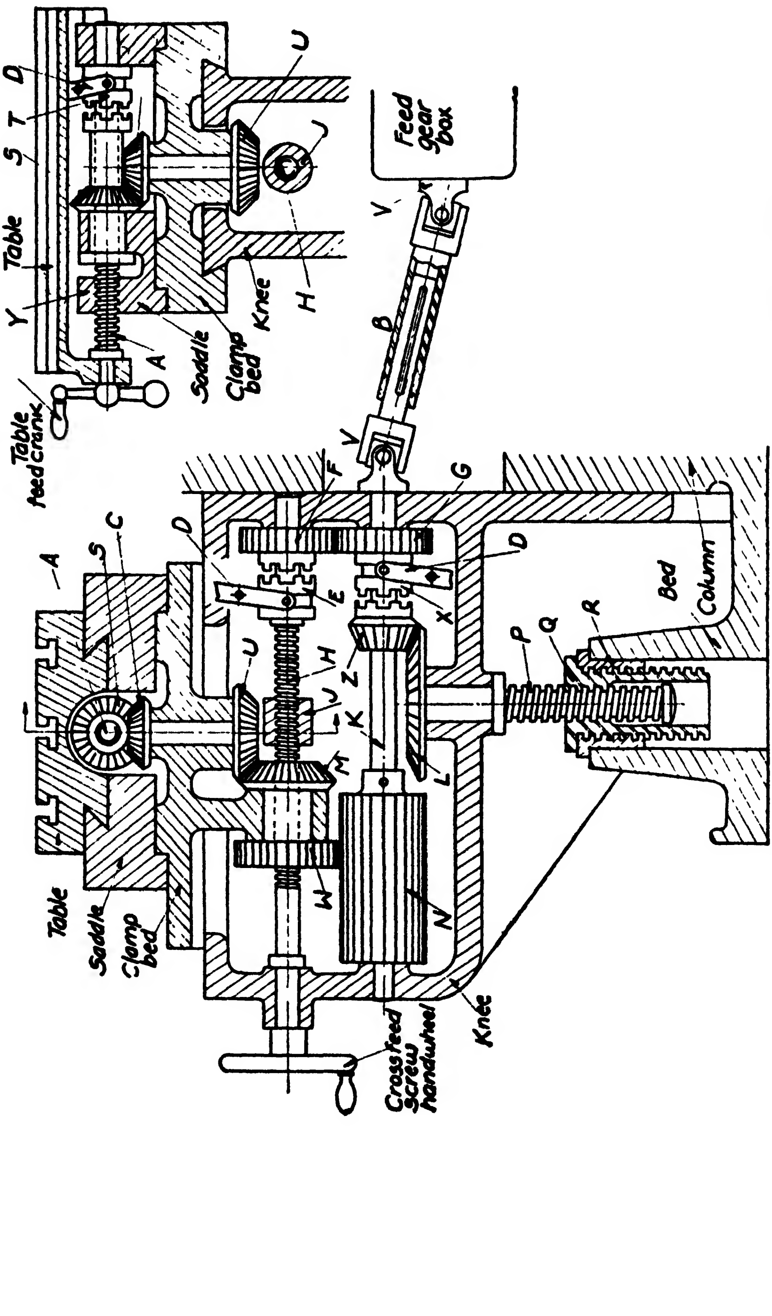


FIG. 13-2. Vertical Sections Through the Knee of a Universal Milling Machine.

to a shaft on which handwheel Q, Fig. 13-1, is fastened.) The **knee is power fed** vertically by moving clutch lever D to engage clutch X with the clutch teeth on bevel pinion Z, and thereby rotating screw P through the medium of bevel gear L.

The clutch E is keyed to the cross-feed screw H which turns in nut J of the clamp bed. To actuate the **cross-feed,** the clutch E is engaged with the clutch teeth on F, causing screw H to turn in nut J.

Gear N is fastened to shaft K, and meshes with gear W which is fastened to bevel gear M. M and W turn in a bearing projecting from the underside of the clamp bed, and also serve as a bearing for screw H. (H is free to rotate or slide in M-W.) Gear M meshes with gear U, which is fastened to a vertical shaft that carries bevel gear C at its upper end. Gear C is in mesh with bevel gear S which has an attached clutch. S is free to rotate on the table feed screw A which turns in the saddle nut Y. To render the **table feed** operative, the jaw clutch T, which is keyed to A, is engaged with the clutch of gear S, causing A to turn in nut Y. To summarize, the knee is driven vertically through gears Z and L and screw P (and Q); the clamp bed and saddle are driven horizontally, and parallel to the spindle, through gears G and F and screw H; and the table is driven horizontally, and either perpendicular or at an angle to the spindle, through gears N, W, M, U, C, and S and screw A. Feed reversal is obtained by shifting a tumbler or idler gear in the feed box.

163. Fig. 13-3 shows several **methods of supporting** and holding **milling cutters.** Old style milling machines and some modern machines for light or medium duty service are equipped with a **taper nose spindle** T. The spindle has a Brown and Sharpe standard taper hole in its nose or front end, into which the taper shank of the **arbor** F fits in a manner similar to a taper shank twist drill. The body of the arbor is cylindrical with a keyway along its entire length. The right end of the arbor has a conical center hole, into which a center fits so as to support the arbor at both ends. The center is carried in an arbor support R, which is in turn supported by an overarm B, Fig. 13-1, extending from the machine column. The arbor support is adjustable along the overarm to accommodate arbors of varied length, and can be securely clamped at any point. The milling cutter or saw is held in position on the arbor by hollow cylindrical arbor collars C, Fig. 13-3, and is driven by the arbor key B. The collars and the saw are clamped together and against the shoulder on arbor F by nut N. The arbor collars serve to position the cutter and help it to resist transverse strain.

Modern heavy duty milling machines are equipped with a **standardized spindle end** as illustrated. The taper hole in the spindle is not a self-holding taper, and serves only to locate the end of the arbor A. The

arbor is seated by turning the draw-in bolt D, which extends through a hole in the spindle, and screws into a threaded hole in the arbor. The arbor is driven by a driving key K on the spindle nose which fits into slots in the arbor shoulder. The arbor support at the extreme right provides a cylindrical bearing for the pilot of the arbor, and in many instances, an intermediate arbor support P, serving as a bearing for an oversize collar Q, is employed.

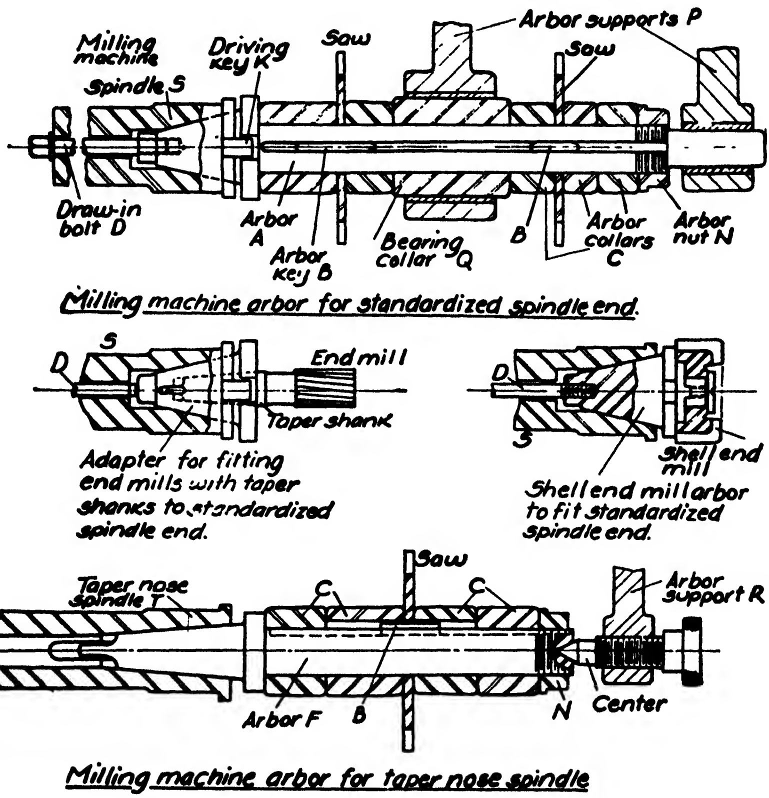


FIG. 13-3. Milling Machine Arbors.

The support D, in Fig. 13-1, is often connected to the knee R by the overarm braces E, for additional rigidity.

164. There are three types of **milling cutters**: hole type cutters which are mounted on the milling machine arbor; shank type cutters which have an integral arbor or shank and are mounted in the hole in the spindle nose, or in an adapter or collet that fits the spindle nose; and face type cutters which are fastened directly to the spindle nose by screws in the body of the cutter. Milling cutters may have teeth on the periphery

only, on the ends only, or on the periphery and ends. **Peripheral teeth may** be *straight* or parallel to the cutter axis, or they may be helical, in which case they are usually, although incorrectly, referred to as *spiral* teeth. Spiral teeth give the cut a shearing action, which reduces the stress on each individual tooth, and prevents the shock that occurs as each tooth of a straight tooth cutter meets the work. Spiral cutters produce much smoother surfaces and require less power to operate than straight-tooth cutters. They tend, however, to induce an end thrust in the cutter, and the hand of the helix should therefore be selected, and the cutter positioned, so that this thrust is towards the milling machine spindle bearing.

Profile type tooth cutters are used for the usual variety of milling operations but there are some standard **form type** tooth milling cutters, such as gear and corner-rounding cutters, that are stocked by manufacturers and are used for unit-production system operations. Except for certain classes of work, profile type milling cutters with comparatively few widely-spaced teeth are preferred to cutters with fine-pitch teeth. Coarse-tooth cutters can remove a maximum quantity of metal in a given time without distressing the cutter or overloading the machine, and with the consumption of less power. Coarse-tooth profile type cutters are also used in preference to fine-tooth profile cutters and form-type cutters, because of the greater chip space between adjacent teeth.

Plain milling cutters are used for machining plane surfaces, and are of cylindrical form with teeth on the periphery only. Cutters under ¾" in width are made with straight teeth as in Fig. 13-5; those with a wider face have spiral teeth as shown in Fig. 13-4. **Helical milling cutters** are plain mills with very few teeth and a very short helical lead. They are particularly efficient on surfacing or slabbing operations of considerable width and depth of cut. Helical mills are also used for light cuts where a very smooth finish is desired, and for frail, light work. **Arbor type helical mills,** in which the cutter is integral with an arbor which may be mounted in the spindle and piloted in the arbor support of the milling machine, are used for milling forms out of solid metal, either from a previously drilled hole or directly in from the end of the work as illustrated in Fig. 13-7.

Metal slitting saws are essentially thin plain milling cutters. Most of the standard saws are made thinner at the center than at the outer edge to provide clearance in milling deep slots. **Screw slotting saws,** however, are of uniform thickness because screw slots are comparatively shallow, and the saws are therefore less expensive than the relieved saw. Tubing saws are made with fine teeth of $\frac{1}{16}$" to $\frac{3}{16}$" pitch, depending upon the wall thickness of the tubing to be cut. **Formed tooth saws** for slitting copper have teeth that are alternately flat and vee-shaped, which

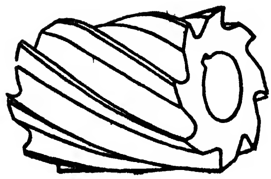


Fig. 13-4. Plain Milling Cutter, Spiral Teeth.

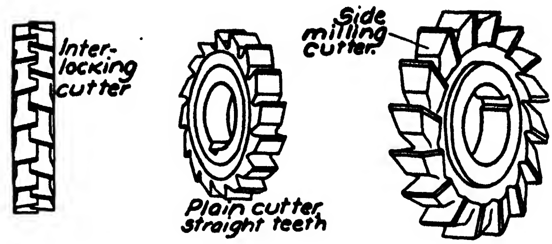


Fig. 13-5. Hole-type Milling Cutters.

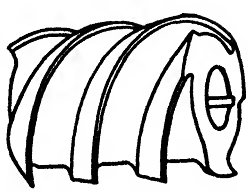


Fig. 13-6. Helical Plain Milling Cutter (Hole Type).

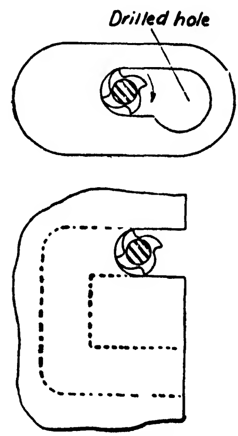


Fig. 13-7. Application of Arbor Type Helical Milling Cutter.

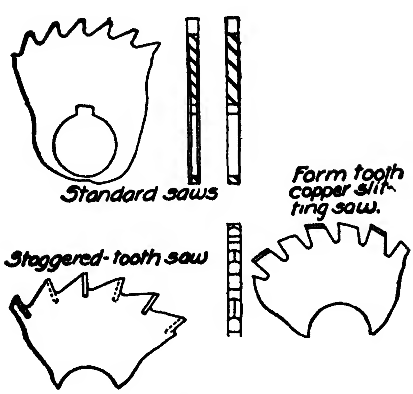


Fig. 13-8. Metal Slitting Saws.

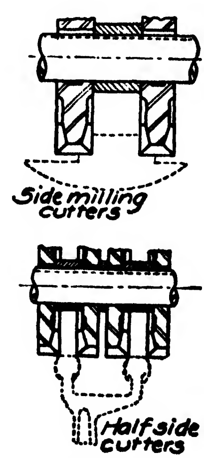


Fig. 13-9. Straddle Milling Applications.

have a tendency to split the chip and force it sideways. Such saws have less tendency to clog and score metals of a soft or tenacious nature than standard saws. **Staggered tooth saws** have alternate side cutting edges, and are used for deep slots and heavy feeds, since they have greater chip clearance than other types of saws. They are not recommended for slots narrower than $\frac{1}{16}''$ as there is a tendency to weave in the kerf.

Side milling cutters are used for slotting, straddle milling and general side or face milling operations. Side milling cutters are similar to plain milling cutters, but have teeth on both sides as well as on the periphery. **Half side milling cutters** are similar to side milling cutters, but have teeth on the periphery and on one side only, and are used for straddle milling operations. Side milling cutters are also made in interlocking pairs as **interlocking cutters** so that slots of standard width may be milled in one operation even after the side teeth are resharpened. The slot width is regulated by shims or washers placed between the hubs of the two parts of the cutter. **Staggered-tooth side milling cutters** have teeth with alternately relieved sides and alternate right and left hand face spirals, and are used for deep slotting and heavy duty milling.

Fig. 13-10 illustrates several standard form type cutters which may be obtained in various stock sizes from cutter manufacturers. **Concave cutters** *A* are used for milling external half circles; convex cutters *D* for milling internal half circles. **Corner rounding cutters** are used for milling external quarter circles, and are made either left hand (*B*) or right hand (*C*), as illustrated. Form cutters for fluting reamers and cutters for spur gear teeth are also stock tool items.

Shank type cutters with an integral shank may be held directly in the hole in a taper nose spindle, or held in an adapter or collet which fits in the spindle nose hole in standardized spindle ends, as shown in Fig. 13-3. Fig. 13-12 illustrates three extensively used shank type cutters which have Brown and Sharpe taper shanks with tang ends. Circular ends with a threaded hole for a milling machine draw-in bolt are also obtainable.

Slotting or two-lipped **end mills** have two cutting lips and are somewhat similar in action to twist drills. They may be used for milling slots with semicircular ends by first feeding to depth and then moving laterally. The depth of cut in solid stock is generally limited to one-half the diameter of the cutters, but deep slots can be produced by successive cuts.

Spiral end mills are similar to plain milling cutters but have teeth on the end face as well as on the periphery. End mills are used for a variety of surfacing operations, particularly for surfaces that cannot be conveniently reached with hole type cutters. The cutter is made with a deep center hole to permit many resharpenings, but cannot be used for

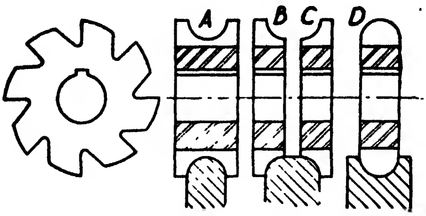


FIG. 13-10. Standard Form Cutters.

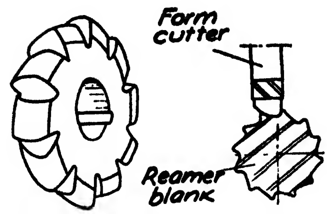


FIG. 13-11. Form Cutter for Fluting Reamers.

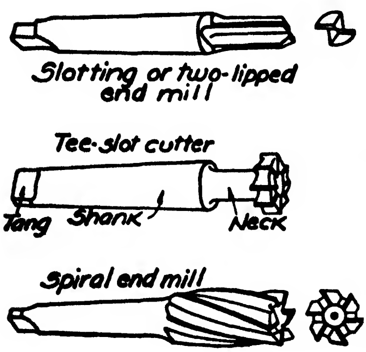
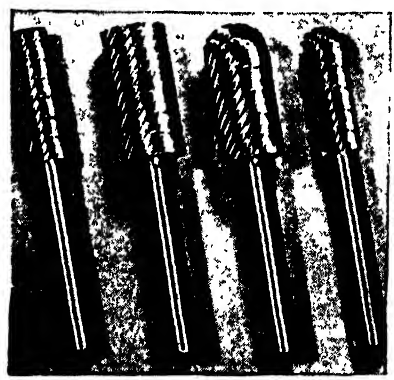


FIG. 13-12. Shank Type Milling Cutters.



George Gorton Machine Co.

FIG. 13-13. Straight-shank Die-Sinking Burrs.

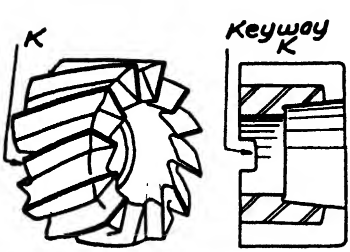


FIG. 13-14. Shell End Mill.

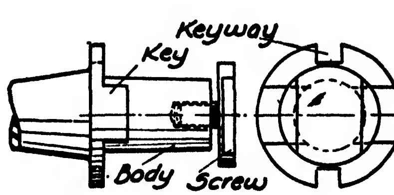


FIG. 13-15. Shell End Mill and Face Milling Cutter Arbor.

originating blind end slots from the solid metal since the teeth do not extend to the center. In machining slots by end milling, it is necessary to drill a starting hole whose diameter is at least equal to the mill diameter. Spiral end mills with straight shanks are extensively used for die-sinking and other similar operations. Straight shank mills are either held in an arbor with a straight hole by a set screw, or held in a spring collet. Fig. 13-13 shows several sizes of square-nose and ball-nose **burrs** which have teeth that are ground from the solid metal after hardening. These burrs are used for finishing cuts on die-sinking and duplicator operations.

Tee-slot cutters are used for milling the base groove or portion of a tee-slot. The body slot must be cut before the tee-slot cutter can be used, and the neck of this cutter must be smaller than the body slot width.

Shell end mills are used in conjunction with an **arbor** (Fig. 13-3 and 13-15), and are more economical than solid end mills of the same size, since one arbor will serve for several cutters and need not be discarded when a cutter is worn out or broken. The **face milling cutter** of Fig. 13-16 is essentially a shell end mill with inserted teeth. Each tooth is held by a taper bushing and a screw which wedges it tightly in place, but will permit adjustment for sharpening. The arbor of Fig. 13-15 has a key that fits the driving slot in the shell end mill or face cutter and a screw to seat the cutter on the arbor body. The keyway of the arbor fits the key in the milling machine spindle nose.

Angular cutters differ from end and side milling cutters in that the straight cutting edges of the teeth are neither parallel nor perpendicular to the cutter axis. Fig. 13-18 shows a single angle cutter with a threaded hole to fit a taper shank screw arbor. Cutters are furnished with a 60° angle, and can be either right hand or left hand, with either right hand or left hand threaded holes. Single angle hole type angular cutters with included angles of 45° or 60°, and double angle hole type angular cutters with included angles of 45°, 60°, or 90°, can also be furnished from stock by most manufacturers.

Face type milling cutters are used for surfacing operations, and consist of a body of cylindrical form with inserted teeth that have cutting edges on the periphery and on one face. The back of the cutter has a cylindrical recess that fits over the spindle nose to locate the cutter. The cutter is held to the spindle nose by four fillister head screws passing through holes in the body of the cutter, and screwing into tapped holes in the spindle nose. The cutter has a key slot in the back that fits the driving keys on the spindle. (The spindle nose is shown in Fig. 13-28.) The peripheral edges of the face milling cutter teeth do most of the cutting, and their action is similar to that of a planer tool, except that they move in a circular instead of a straight path. The face teeth theoretically do not

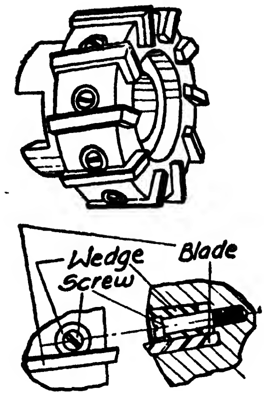


Fig. 13-16. Face Milling Cutter with Inserted Teeth.

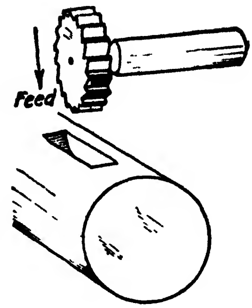


Fig. 13-17. Straight-shank Woodruff Keyseat Cutter.

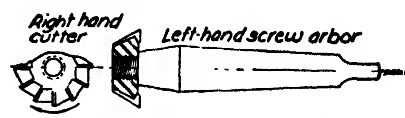


Fig. 13-18. Single Angle, Threaded Hole Milling Cutter and Screw Arbor.

Goddard & Goddard Co

Fig. 13-19. Milling Right and Left Keyways in a Shaft with Two 8" Diameter Angular Cutters with Helical Teeth.

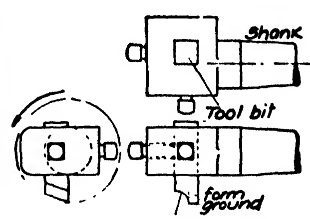


Fig. 13-20. Fly Cutter.

cut at all, but actually they remove a small amount of stock left from the deflection of the work or the cutter, as they sweep over the surface machined by the peripheral teeth.

Fly cutters are single-toothed form cutters. Since one tooth does all the cutting, it reproduces its shape very accurately in the work, but a very fine feed is required. The cutter can be easily ground from tool bit stock, and often serves as a means of milling intricate shapes that will not warrant the expense of special formed cutters.

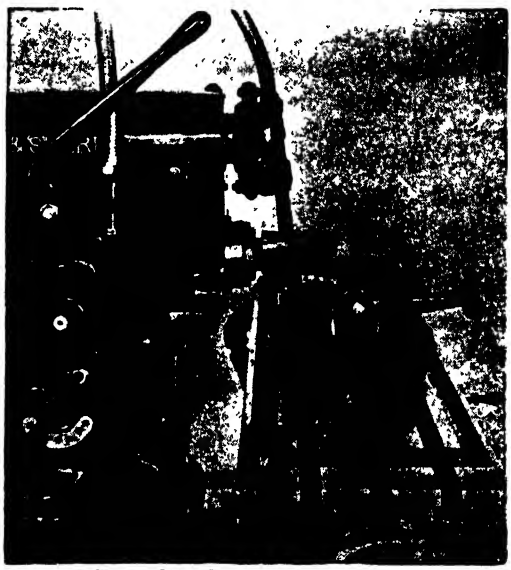
Milling cutters are made of either carbon or high-speed steel. High-speed steel cutters are so much more efficient than carbon steel cutters that the application of the latter is limited to occasional jobs where the cutter is used so infrequently that it is more economical to spend more time on the milling operation than to carry the initial cost of the cutter. Many shank type cutters have high-speed steel cutting ends and carbon steel shanks welded together. Inserted tooth cutters generally have high-speed steel blades and machinery steel bodies. Tungsten-carbide tipped cutters are coming into extensive use, but require milling machines of sufficient rigidity, ample power, and sufficiently high feed and speed ranges to warrant the additional initial and sharpening costs of this material.

165. Cutting speeds on the milling machine depend upon the character of the work, the type of cutter, the condition of the machine, and in many instances, upon the experience and ability of the machine operator. A reasonable basis for surface cutting speeds, in feet per minute, for high-speed steel cutters, is as follows: annealed tool steel, 60 to 80; machinery steel and cast iron, 80 to 100; and brass, 150 to 200. Carbon steel cutters should operate at approximately half these speeds. **Coolants** such as lard oil and emulsions of water and soluble oils are used for milling steel and brass. Cast iron and bronze are generally milled dry, since the chips tend to mix with the fluid to make a sticky mass that clogs the cutter teeth. Compressed air is sometimes used to advantage in cast-iron milling.

Because the production rate of a milling machine depends upon the rate of feed, it is desirable to use as high a feed rate as possible. **Feed rates** are expressed in two ways: inches per minute, or thousandths of an inch per revolution of the spindle. Delicate or fragile work requiring an accurate finish will need fine feeds, while heavy work, from which a considerable amount of metal is to be removed, can be subjected to coarse feeds. The type of cutter employed also has a definite bearing on the feed; for instance, in milling through slots, a side milling cutter can obviously stand a much coarser feed than an end mill. Roughing and finishing cuts may be required for efficient metal removal and satisfactory finish. In such a case, the cutting speed is generally the same for both cuts but the finishing

cut feed is much finer than the roughing cut feed. A good commercial finish can usually be obtained by using a feed rate of from .030" to .050" per revolution of the cutter. Finer feeds, such as .015" per revolution, will result in an excellent finish.

166. A **plain column and knee type milling machine** is similar to a universal milling machine, but has no swivelling arrangement for the table. The saddle and clamp bed are an integral unit, and the table always moves on the saddle at right angles to the spindle. The plain milling machine is less expensive than the universal miller and is more rigid. Fig. 13-22



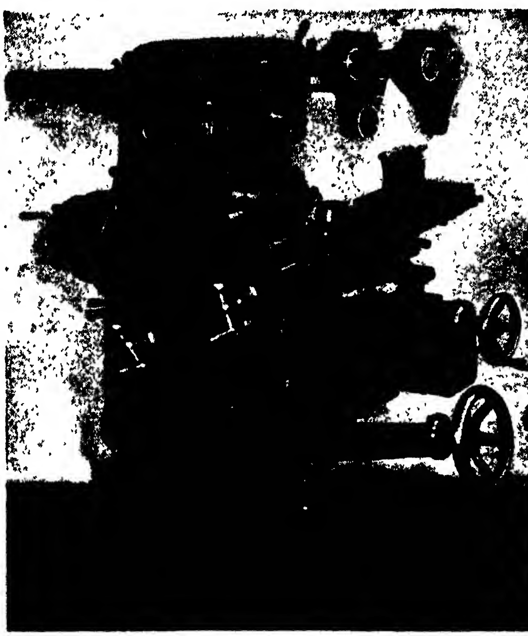
Brown & Sharpe Mfg. Co.

FIG. 13-21. Facing Operation on a Plain Milling Machine, Using a Shell End Mill.

shows a recently-developed **Omniversal** or tool-room milling machine. It is similar to a universal miller, but the knee is supported by an intermediate saddle on the face of the column, and can be adjusted and set about an axis parallel to the spindle. The table can therefore be tilted in two planes for almost any operation requiring compound angle milling.

Column and knee type machines can be obtained with a constant-speed motor drive in which spindle speed changes are obtained by change gearing in the column. Belt-driven machines, in which spindle speed changes are obtained by a cone pulley drive either with or without back gears, are also used, particularly in the smaller machines such as the **bench milling machine** shown in Fig. 13-37. Cone and back-gear driven milling machine spindles are similar in principle to belt-driven engine lathe spindles.

Fig. 13-23 shows a **vertical spindle milling machine** using a face milling cutter with inserted teeth to mill the upper surface of a cast iron block. A vertical spindle milling machine is essentially a plain column and knee type machine with a vertical spindle mounted on an adjustable head. Spindle heads with power feed and a micrometer dial with adjustable stops, as illustrated in Fig. 13-23, are also available. In some vertical millers, the spindle is carried in an extension of the column; in others, it is mounted in a swivelling head that is pivoted on the column so that



Brown & Sharpe Mfg. Co.

FIG. 13-22. Omniversal Milling Machine.

angular milling can be performed. Vertical spindle milling machines are adapted to a wide variety of work, particularly face and end milling operations.

167. Milling machine work is held in a vise whenever possible, since work may be set up more quickly than by using clamps or bolting the work to the table. Hole type cutters are used in preference to end milling cutters, although face mills will afford production rates that compare favorably with those attained by peripheral cutters.

168. **Milling machine spindle attachments** are employed for milling, drilling and boring operations on column and knee type milling machines.

Kearney & Trecker Corp.

FIG. 13-23. Vertical Spindle Milling Machine.

Kearney & Trecker Corp.

FIG. 13-24. Milling an Angular Surface.

The attachment may be used for machining angles, undercuts, and other surfaces that are difficult or impossible to reach with standard equipment. It is also used in place of a vertical milling machine on small and medium sized work.

Figs. 13-24 to 13-26 show some applications of a high-speed **universal milling attachment** that is mounted on the column and overarms of a plain milling machine. The attachment has two circular graduated bases so that the spindle can be set at almost any angle with the milling machine table. The spindle is carried in anti-friction bearings in a sleeve which permits an axial hand adjustment of 1½". The spindle is driven by a pair of spiral bevel gears driven by a splined shaft geared to the milling machine spindle. Fig. 13-24 shows how the attachment may be set at some distance from the column. The splined driver shaft is shown directly under the overarms. Fig. 13-27 shows another attachment used only for light vertical milling. Slotting and thread milling attachments are also available.

Kearney & Trecker Corp.

Fig. 13-25. Milling the Base Groove of a Tee Slot.

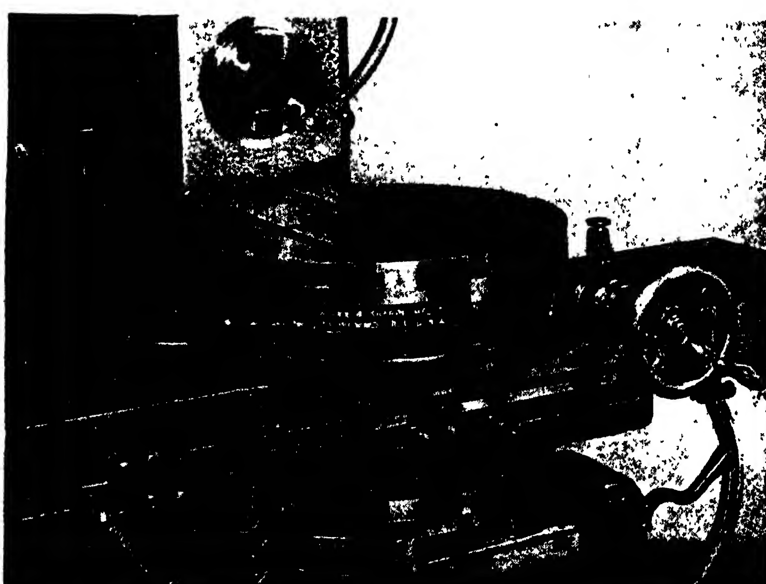
Kearney & Trecker Corp.

Fig. 13-26. Drilling on the Milling Machine.

Brown & Sharpe Mfg. Co.

FIG. 13-27. Light Vertical Milling Attachment, Using an End Mill to Finish the Sides of a Slot.

169. **A rotary milling attachment** consists of a circular table which is supported by and rotates on a base which is bolted to the milling machine table. The rotary table is driven by a worm gear and worm, which is in turn rotated by a handwheel and crank in hand attachments, or by a universal shaft drive from the table in power attachments. The rotary attachment is used for circular milling and for indexing, for which graduations are provided at the edge of the table. By means of a lead attachment, it is also possible to mill face cams, spirals, and scrolls on a rotary attachment. In such operations, the rotary and the milling machine tables are geared together as in spiral milling, so that the machine table has

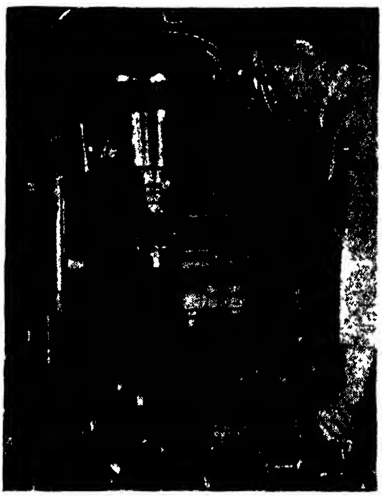


Brown & Sharpe Mfg. Co.

FIG. 13-28. Rotary Milling Attachment with Hand Feed.

a definite longitudinal movement relative to the rotation of the rotary table.

Fig. 13-31 shows a method of **finishing** grooved **face cams** on a milling machine. The groove is first roughed out with an end mill or a slotting mill to within $\frac{1}{16}''$ of size, and then placed on a rotary table for milling the circular portion of the cam between lines AC and BC. A special end-cutting mill whose body diameter is ground to the groove width is used for this operation, and three or four cuts are required to finish



Kearney & Trecker Corp.

FIG. 13-29. Milling the Grooves in a vee-belt sheave with a power driven rotary attachment on a vertical milling machine.

Kearney & Trecker Corp.

FIG. 13-30. Milling four accurately spaced spiral grooves in a locking plate, using a rotary table and a lead attachment.

the full depth of the groove. A hardened steel template is then attached to the cam, which is clamped to a milling machine table, and the balance of the groove is finished in three or four cuts using the end-cutting mill. The body of the mill is kept against the edge of the template by the combined hand operation of the table and saddle feed screws. The finishing operation requires considerable skill, since the work will be defective if the cutter body is allowed to move away from the edge of the template during the operation. On the other hand, there is some danger of shifting the work or breaking the cutter if the mill is jammed too hard against the edge of the template.

170. Indexing is one of the most important applications of the milling machine. Fig. 13-32 illustrates a set of universal index centers

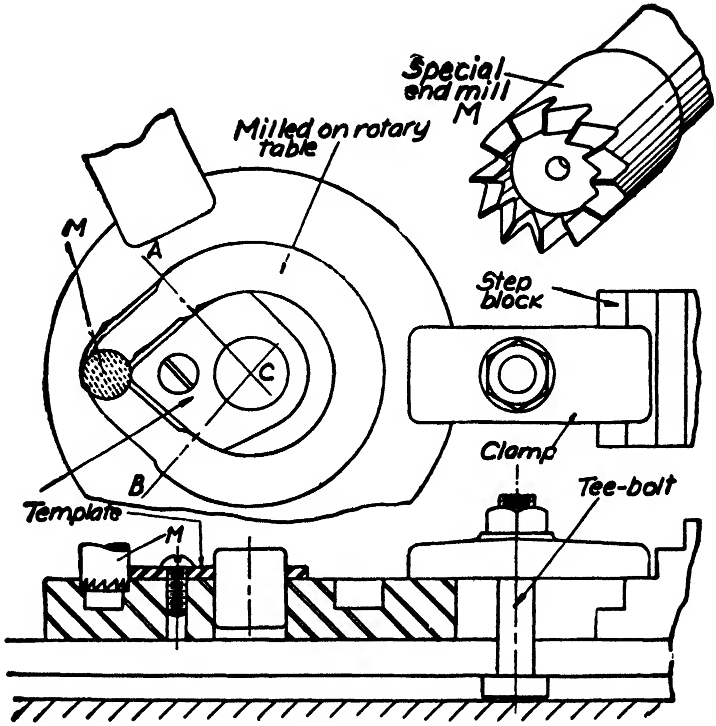
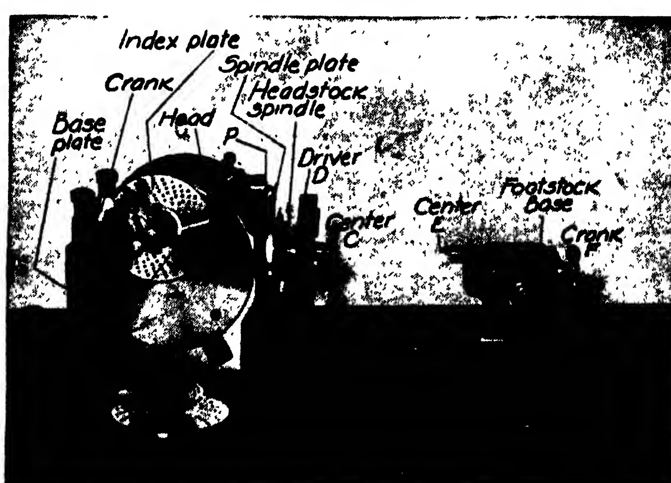


FIG. 13-31. Cutting face cams on a milling machine.



Brown & Sharpe Mfg. Co.

FIG. 13-32. Universal Index Centers.

with the necessary auxiliary equipment. The **headstock** consists of a hollow head in which a spindle carrying a 40 tooth worm wheel is mounted. A single-threaded worm, which may be rotated by a crank, is in mesh with the worm wheel. The head casting has bearings at each side that fit the contours of a base plate which can be clamped to the surface of a milling machine table by tee-bolts. The front end or nose of the spindle is threaded to carry a chuck if desired, and has a taper hole for a center or an arbor. The axis of the head bearing on the base plate intersects and is perpendicular to the axis of the spindle. It is possible to swing the head in its bearings so that the nose of the spindle can be set to any angle from 10° below the horizontal to 5° beyond the perpendicular. Graduations on the side of the head indicate the angular elevation to half degrees. The head can be rigidly clamped in any position.

The work to be indexed can be held on a mandrel or arbor in the spindle nose of the headstock, as illustrated in Fig. 13-33, 13-34 and 13-35, or it can be held in a chuck which is screwed to the spindle as shown in Fig. 13-36. Many parts, however, are held between the headstock and footstock centers, as illustrated in Fig. 13-37, or on a mandrel between these centers as shown in Fig. 13-38. A **footstock** is shown in Fig. 13-32. The base is bolted to the milling machine table, and carries a sleeve which holds the footstock center *E*. The sleeve may be adjusted axially by the crank *F*. The center can be adjusted vertically, and can be set at an angle out of parallelism with the base when it is desired to mill tapered work.

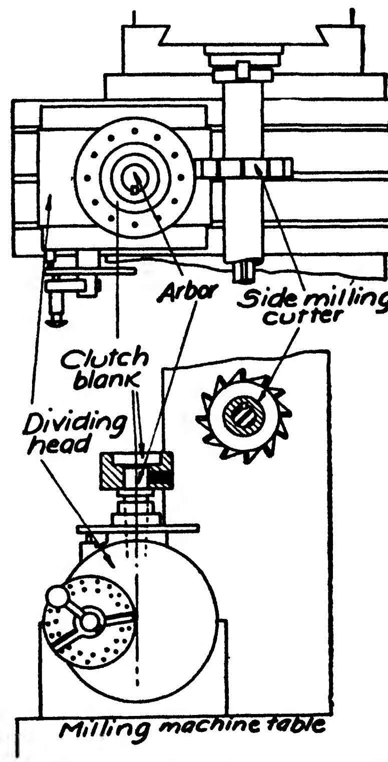


Fig. 13-33. Cutting Jaw Clutch Teeth on a Milling Machine.

There are four **methods of indexing**: direct, plain, compound, and differential. In **direct indexing**, the plate on the spindle and the locking pin *P* are used. This plate has twenty-four equally spaced holes, and angular divisions of 15° or multiples thereof can be obtained by withdrawing pin *P* and moving the spindle to the next hole in the plate. Direct indexing is obviously limited to dividing a circle into 2, 3, 4, 6, 8, 12, and 24 parts.

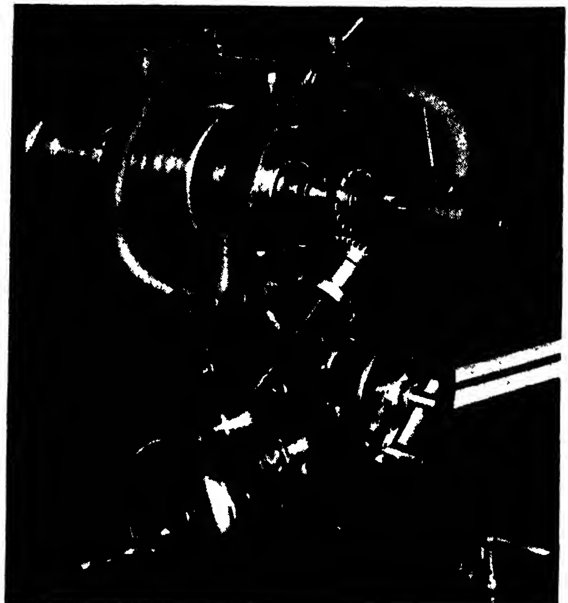


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FIG. 13-34. Cutting a Bevel Gear on a Universal (Bench) Milling Machine, Using a Differential Indexing Head.

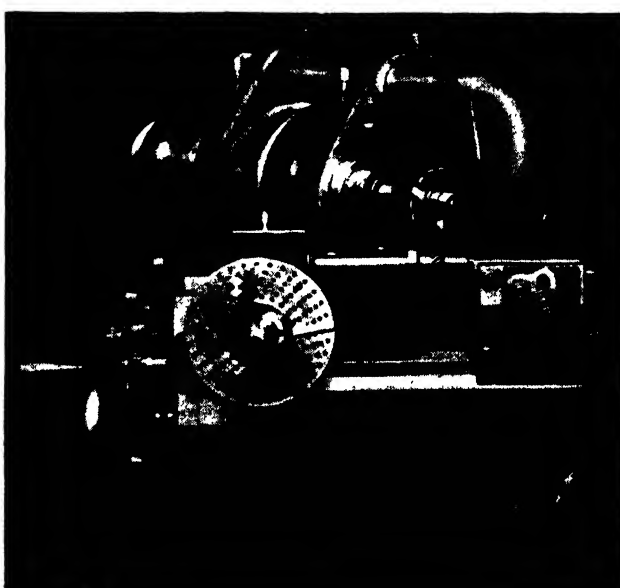

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FIG. 13-35. Cutting a Helical Gear on a Universal Milling Machine, Using a Spiral Head and a Taper Shank Arbor.

Plain indexing makes use of the index plates illustrated in Fig. 13-32. One of the plates is mounted on the bearing for the worm shaft, and is locked in place by a pin similar to *P*, Fig. 13-32. The index plates have six series of holes as follows:

Plate No. 1	15, 16, 17, 18, 19, 20
Plate No. 2	21, 23, 27, 29, 31, 33
Plate No. 3	37, 39, 41, 43, 47, 49

The crank arm is adjustable so that the locking pin in the crank handle can fit any of the series of holes in a particular plate.

To illustrate plain indexing, suppose it is desired to cut 60 slots in a cylindrical bar that is mounted between the headstock and foot-stock centers. The number one plate is used and the crank is set to fit the 15 hole circle. If the crank is turned from one hole on this circle to the next hole, the crank will have made $\frac{1}{15}$ of a revolution. Since the worm and worm gear ratio is 40:1, the spindle will therefore make $\frac{1}{15} \times \frac{1}{40}$ of a turn, or $\frac{1}{600}$ of a turn. In order for the spindle to index $\frac{1}{60}$ of a turn, it is therefore necessary to move the crank 10 spaces at a time. The crank will be moved from hole No. 1 to hole No. 11, to hole No. 21, etc. The procedure is more accurate and affords easier manipulation than direct indexing.

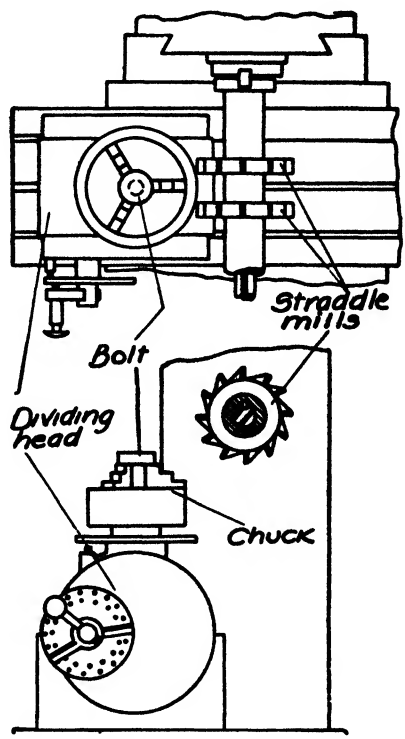

Fig. 13-36. Straddle Milling Bolt Heads.

The sector, Fig. 13-32, is used to eliminate the necessity of counting index holes for crank movements. It consists of two arms that can be locked in any position with respect to each other, but is reasonably free as an entire unit to move about the crank axis. If the crank is turned clockwise, in the example above, the left arm of the sector is brought against the crank pin while it is in hole No. 1, and the right arm is set so that it is just past hole No. 11. On the first indexing operation, the crank is moved to hole No. 11, indicated by the sector arm, and the locking pin

allowed to slip into the hole. The sector is then swung so that its left arm is against the pin, thereby placing the right arm of the sector just to the right of hole No. 21. When the crank is again indexed and its pin locked in hole No. 21, the left arm of the section is swung against the pin and the right arm locates hole No. 31.

If a 27 tooth gear is to be cut on the milling machine, it is necessary to use the 27 hole circle on the number 2 plate. If the crank is moved

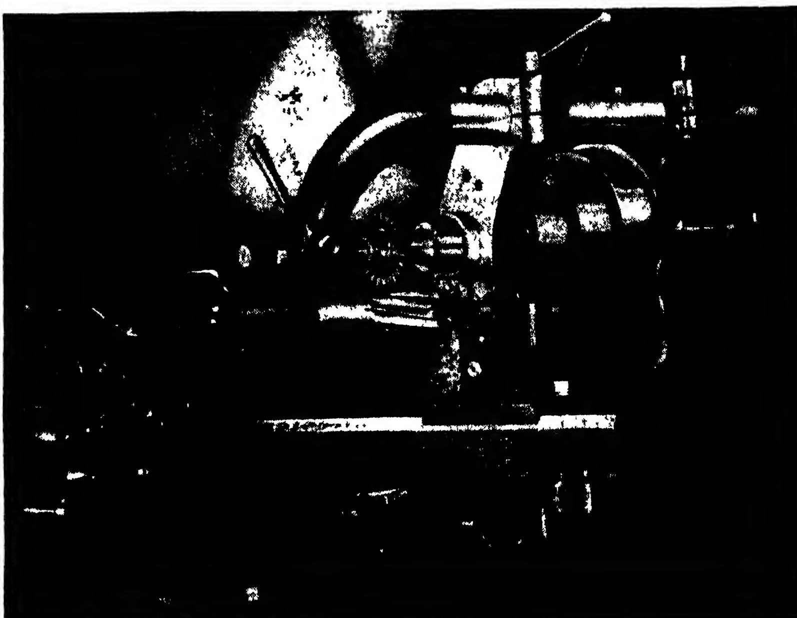

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Fig. 13-37. Cutting the Helical Flutes in a Taper Shank End Mill, Using a Spiral Head and a Side Milling Cutter.

from one hole in this circle to the next, the spindle will rotate $\frac{1}{27} \times \frac{1}{40}$ turn. In order to rotate the spindle $\frac{1}{27}$ turn, it is necessary to move the crank through an arc of 40 spaces, or one complete turn and 13 additional spaces on the index plate. The sector arms should be set so as to encompass 13 spaces or 14 holes. In indexing, the left arm of the sector is placed against the crank pin, and the crank is rotated one turn in a clockwise direction, passing over the left arm of the sector until it is located in the hole nearest the right arm of the sector. The sector is then swung so that the left arm rests against the pin in its new position, and is therefore ready for the next indexing operation.

With the three index plates supplied, plain indexing can be used for all divisions up to 50; even numbers, except 96, up to 100; and many others. Two methods of indexing, compound and differential, are used for divisions that cannot be obtained by plain indexing. In **compound indexing,** the crank is turned as in plain indexing and locked in place, but the plate locking pin is then withdrawn and the plate rotated a definite amount to give a combination of motions that will afford the desired division. The method is tedious and time-consuming, and is rarely employed except when differential indexing equipment is not available.

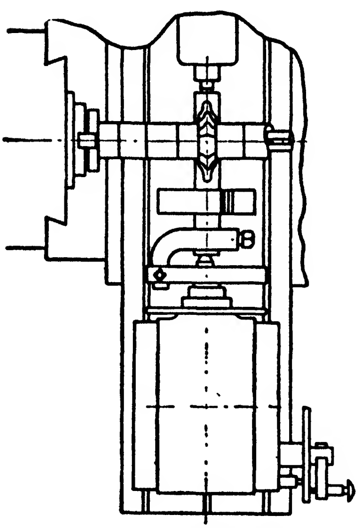

FIG. 13-38. Plain Milling Machine Set-up for Cutting Spur Gear.

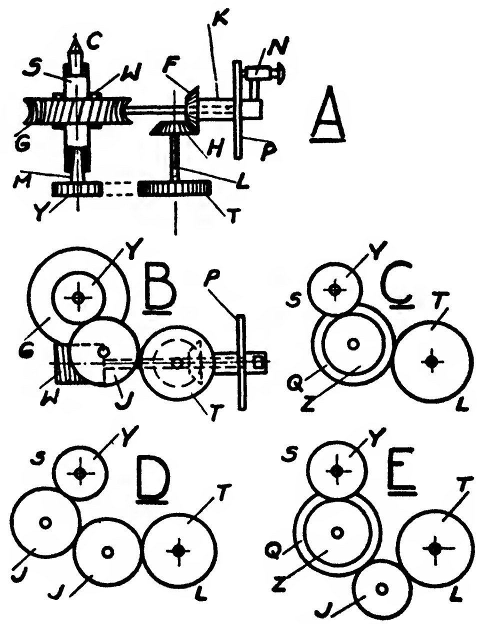

FIG. 13-39. Differential Indexing Elements.

In **differential indexing,** a dividing head that differs somewhat from the head of Fig. 13-32 is used. A diagrammatic representation of a differential head is shown in Fig. 13-39. The index plates P are mounted on a worm shaft bearing K, which is free to turn on the worm shaft and has a miter gear F fastened to it. F meshes with a miter gear H on shaft L. The rear end of spindle S has a tapered hole to fit a stud M. Change gears Y and T are fastened to M and L and connected by idler or compound gearing. If the plate locking pin in the head is withdrawn, and the crank N rotated, the spindle S is turned by worm W meshing with worm wheel G. This causes gear Y to rotate, driving gear T, which causes plate P to

rotate. The crank must therefore move through a different arc than it would if the plate P were fixed.

To illustrate differential indexing, suppose 271 divisions are required. The number 2 index plate is placed on K, and the crank N is set to the 21 hole circle. The following change gears are generally furnished with differential indexing heads:

24, 24, 28, 32, 40, 44, 48, 56, 64, 72, 86, 100.

Referring to Fig. 13-39, A and B, $Y=72$, $T=56$, $J=24$.

For each $\frac{1}{271}$ turn of the spindle, the crank must move through $\frac{40}{271}$ turns. At the same time the index plate is being turned through the train Y, J, T, H, and F. The index plate therefore rotates $\frac{1}{271} \times \frac{72}{56}$ turns for each crank movement in the same direction as the crank. The relative motion of the crank with respect to the index plate P is therefore equal to the difference of the absolute motion of the crank, and the absolute motion of the index plate, or $\frac{40}{271} - \frac{\frac{72}{56}}{271} = \frac{1}{7}$. As a 21 hole plate is employed, the crank must be moved 3 spaces at a time, or from hole No. 1 to hole No. 4 to hole No. 7.

Suppose 289 divisions are required. The arrangement is the same as in the preceding example, but two 24 tooth idlers J, as in Fig. 13-39, D, are used. For $\frac{1}{289}$ spindle turn, the absolute motion of the crank is $\frac{40}{289}$ turns. The absolute motion of the plate–is $\frac{\frac{72}{56}}{289}$ turns in a direction opposite to the crank motion. The relative motion of the crank and plate is therefore $\frac{40}{289} + \frac{\frac{72}{56}}{289} = \frac{1}{7}$, and the crank is therefore moved three spaces for each indexing operation as before.

Sometimes a compound idler QZ, as illustrated in Fig. 13-39, C or E, must be used. Suppose 321 divisions are required. The 16 hole circle on the number 1 plate is placed on the worm bearing K, and the following change gears (Fig. 13-39 E) are used: $Y=24$, $Q=24$, $Z=64$, $T=72$, and $J=28$. The absolute motion of the crank is $\frac{40}{321}$ turns, and the absolute motion of the plate is $\frac{1}{321} \times \frac{24}{64} \times \frac{24}{72}$, in a direction opposite to the crank motion. The relative motion of the crank and the plate is therefore equal to $\frac{40}{321} + \frac{24 \times 24}{321 \times 64 \times 72} = \frac{1}{8}$. As a 16 hole circle is used, the crank must be moved two divisions at a time, or from hole No. 1 to hole No. 3 to hole No. 5.

The only effect of idlers J is to reverse the direction of rotation of the plate, and change gears of any convenient size may be employed. The

compound idler Q-Z and the idlers J are free to rotate on studs which are carried on slotted arms as illustrated in Fig. 13-34. Tables for determining change gears, sector settings and plate selection for divisions from 2 to 382 divisions may be found in shop handbooks and trade manuals.

171. Fig. 13-36 illustrates how square and hexagonal bolt heads are cut on a milling machine equipped with a dividing head, by using two side milling cutters set to the short diameter, or distance across flats, of the square or the hexagon. The bolt W is held in a universal chuck which is screwed to the spindle nose of the dividing head. This operation is known as **straddle milling.** Square and hexagonal heads can also be cut by using one side milling cutter, which eliminates the time consumed in setting up two cutters. Hexagonal bolt heads can be straddle milled in five operations, however, while eleven are required if one cutter is used, as illustrated in Fig. 13-40. In the figure, C represents a cutting and X an indexing operation.

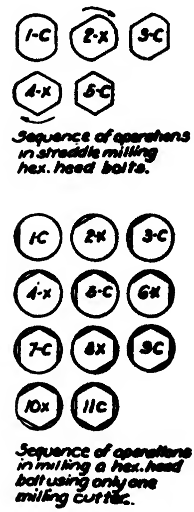

FIG. 13-40. Sequence of Operations in Milling Hexagonal Bolt Heads.

Fig. 13-33 and Fig. 13-41 show how the clutch teeth for a square jaw clutch are shaped. The blank is mounted on a special arbor to which it is keyed. Five operations are required for a three jaw clutch.

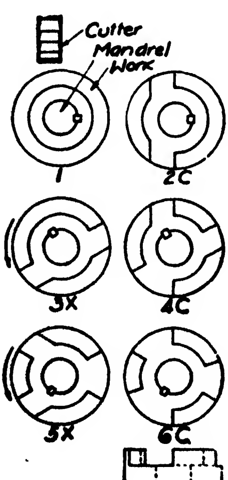

FIG. 13-41. Sequence of Operations in Milling a Three-tooth Straight Jaw Clutch.

172. Spur gears may be cut on either a universal or a plain milling machine equipped with a dividing head. The machine and dividing head are set up as illustrated in Fig. 13-38. The gear blank is mounted on a mandrel which is carried between the headstock and footstock centers. The mandrel is positively driven by a dog whose tail fits the driver D, Fig. 13-32. A form-type gear cutter of the correct pitch and shape is mounted on the machine arbor, and the milling machine saddle is adjusted so that the axis

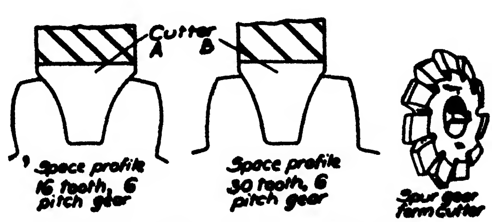

FIG. 13-42. Spur Gear Cutting.

of the mandrel is in the same vertical plane as the central plane of the cutter. The machine knee is then elevated until the cutter just touches the outer periphery of the gear blank; the table in then brought forward so that the cutter is clear of the blank, and the knee is elevated a distance equal to the whole depth of the tooth. The first cut is then taken thereby forming one side each of two adjacent teeth. The table is then brought forward, the dividing head is indexed, and the second cut is taken, completing one tooth and shaping one side of the next tooth. The process is continued until all the tooth spaces have been cut.

The **shape of the tooth space** in gears of the same pitch and tooth proportion varies with the number of teeth in the gear as illustrated in Fig. 13-42. For reasonably accurate gear cutting, eight different cutters are required to cut all sizes of gears of a given pitch. A No. 1 cutter will cut all gears having 135 or more teeth; a No. 2 cutter will cut gears having from 55 to 134 teeth; a No. 3 cutter will cut gears having from 35 to 54 teeth; and a No. 8 cutter will cut gears with 12 or 13 teeth. The cutter forms are correct for the lowest number of teeth in each range. If a more accurate tooth form is desired for cutting gears near the higher part of the range, seven additional half-number cutters can be obtained. A No. 1½ cutter, for example, will cut gears having from 80 to 134 teeth, and a No. 2½ cutter will cut gears having from 42 to 54 teeth. For still greater degrees of accuracy, cutters of the proper shape for an exact number of teeth can be furnished by most manufacturers at short notice, although these are not generally carried in stock.

A **rack** may be cut by holding the blank parallel to the arbor axis in a vise, and using the graduations on the dial of the saddle screw to move the blank a distance of a circular pitch for each tooth space. A special device known as a rack milling and indexing attachment may, however, be obtained to facilitate this work for quantity production.

Fig. 13-34 shows a universal bench milling machine set up with a differential head to cut the teeth of a **bevel gear.** As bevel gear teeth spaces are thinner and shallower at the inner edge of the face than at the outer edge, a spur gear cutter of proportionately smaller size is used, and three cuts are made to finish each tooth space. The first cut is made straight through and shapes the inner end of the tooth space. The second and third are made at each outer edge of the space, by setting the cutter off center and slightly rotating the blank to correspond. Even after these three cuts are made, it is generally necessary to correct the small ends of the teeth by filing.

173. Spiral milling is the process of cutting helices on a universal milling machine by connecting a universal dividing head by change gears to the table lead screw, so that the dividing head spindle rotates in con-

junction with the movement of the table. Fig. 13-43 shows the principles involved in spiral milling. The table lead screw R rotates in the fixed nut in the ' .ddle and moves the table. A gear X is keyed to the screw R, and drives gear T on shaft L through idler U-V which may be a compound gear as illustrated, a single idler J, or a pair of idlers for reverse rotation. The worm wheel G on the spiral head spindle S is driven by worm W, which is in turn driven by crank N. Crank N is locked to plate P which is fastened to the worm bearing K and miter gear F. The change gears employed for differential indexing can be employed for gearing the head for spiral milling. The table lead screw generally has a pitch of ¼″.

As an example, consider that a helix with a lead of 8″ is required. Since each turn of the table lead screw advances the work ¼″ axially, the lead screw must turn 32 times while the work turns once. As the worm shaft of the dividing head must turn 40 times while the spindle turns once, the gear T, Fig. 13-43, must turn 40 times while gear X, fastened to R, turns 32 times. If the 100 tooth change gear is selected for X, the 40 tooth gear for U, the 32 tooth gear for V, and the 64 tooth gear for T, it is found that if T turns 40 times, the compound UV will turn $\frac{40 \times 64}{32}$ or 80 times. The lead screw R will therefore turn $\frac{40 \times 80}{100}$ or 32 times, giving a lead of 8″, and a right hand helix as illustrated. The milling machine saddle is of course swivelled to the proper helix angle as measured with respect to the axis of the work. A left hand helix can be cut by using the same gearing with an idler J between T and V, with the table set at the proper angle.

Consider that it is desired to cut a right hand helical gear with 20 teeth, 5 normal diametral pitch, and a pitch diameter of 4.472″. The helix angle of the gear is found by:

$$\cos A = \frac{\text{number of teeth}}{\text{pitch} \times \text{pitch dia.}}$$

$$\cos A = \frac{20}{5 \times 4.472}$$

$$\therefore \quad A = 26°34'$$

The lead of the helix is found by:

$$\text{Lead} = \pi \times \text{pitch dia.} \times \tan A$$

$$\text{Lead} = \pi \times 4.472 \times .5 = 7.025$$

The table is set at an angle of 26°34′ as illustrated in Fig. 13-43, and the following gears are selected: T-72, V-44, U-24, and X-56. Then, if the spindle turns once and T has 40 turns, the lead screw R makes

$\frac{40 \times 72 \times 24}{44 \times 56}$ turns, or $\frac{2160}{77}$ turns. The table movement for one turn of the dividing head spindle is therefore $\frac{2160}{77} \times \frac{1}{4}$ or 7.013", which is as close to the required lead as can be obtained with the change gears supplied.

In order to cut the entire gear, it is necessary to index the dividing head in the same manner as in plain indexing. After the first helical tooth space has been cut, the cutter is returned to its original position, the crank pin

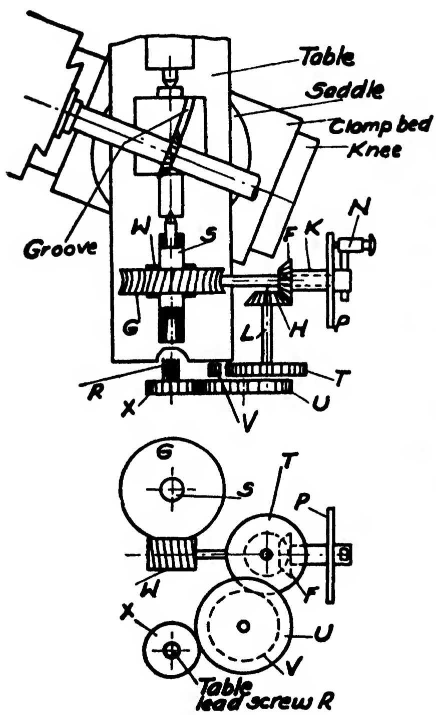

FIG. 13-43. Spiral Milling Elements.

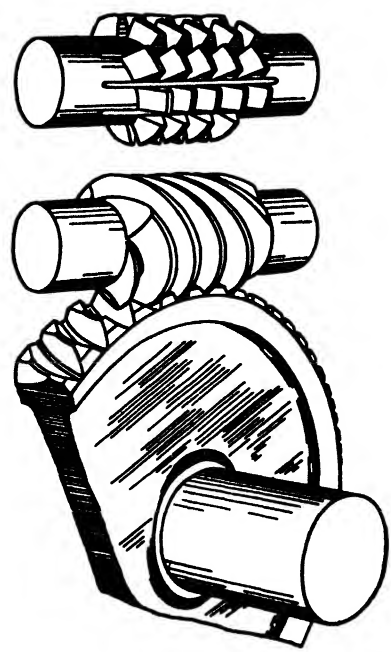

FIG. 13-44. Worm Gear Set and Worm Wheel Tooth Hob.

is withdrawn from the plate, and the crank is turned twice. The crank pin is then allowed to enter the plate hole, the feed mechanism is started again, and the second tooth space is cut.

174. Worm wheel or **worm gear teeth** are generally cut in two stages on the milling machine. On account of the curved face of the worm wheel, the teeth are generally finished by a **hob**, which is a cutter that is practically a duplicate of the mating worm, as shown in Fig. 13-44. In the first stage, the worm wheel is set up like a spur gear but with the milling

machine table set at an angle corresponding to the helix angle of the worm wheel. The tooth spaces are roughed out, or *gashed,* by using a spur gear cutter of the proper pitch and cutter number. The cutter is placed above the worm wheel, and the tooth spaces are cut to within 1/16″ or ⅛″ of size by using the vertical feed of the knee. The milling machine table is then set perpendicular to the arbor axis, and the driving dog is removed from the worm wheel mandrel so that the work is free to rotate on the index centers. A worm gear hob is then placed on the arbor, and the knee is fed vertically upwards until the hob has cut its full depth. The hob drives the blank as it cuts and finishes the tooth space gashes.

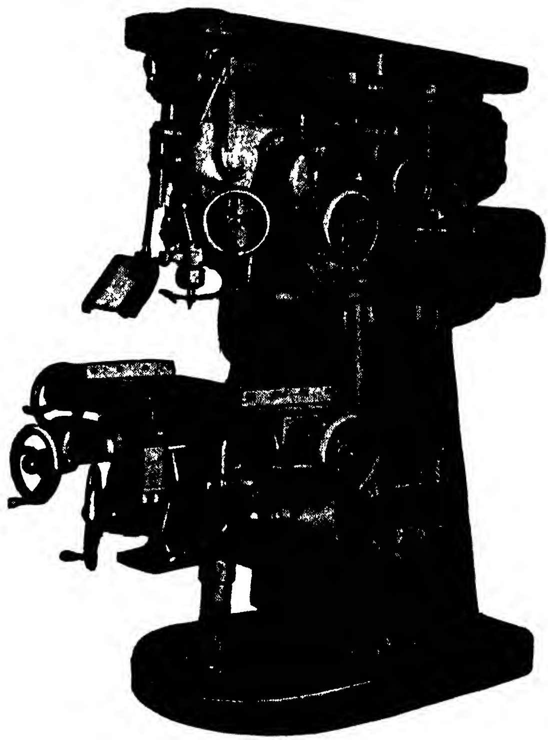

FIG. 13-45. Universal Die-sinking Machine.

For helices in which the lead is short as compared to the diameter, as in worm and drum cam milling, it is inadvisable to drive the spiral head from the table lead screw on account of the danger of straining or distorting the screw. An effective method of cutting short lead helices is to disconnect the power feed to the lead screw, apply a two-handed attachment to the spiral head index crank, and rotate the spiral head by hand thereby driving the lead screw.

175. Fig. 13-45 shows a **universal die-sinking machine,** which is a specialized vertical spindle milling machine, and is used for ***sinking*** or cutting die cavities for drop forged or die-cast work. The table, saddle, and knee of the machine are essentially like those of a plain milling machine. The spindle is carried in an oscillating head which is mounted on two large eccentrics *E*, Fig. 13-46. The eccentrics may be rotated by hand or by power through the internal gears *G* and the driving pinions *P*. The head *H* and the cutter end may therefore move in a circular path in a plane perpen-

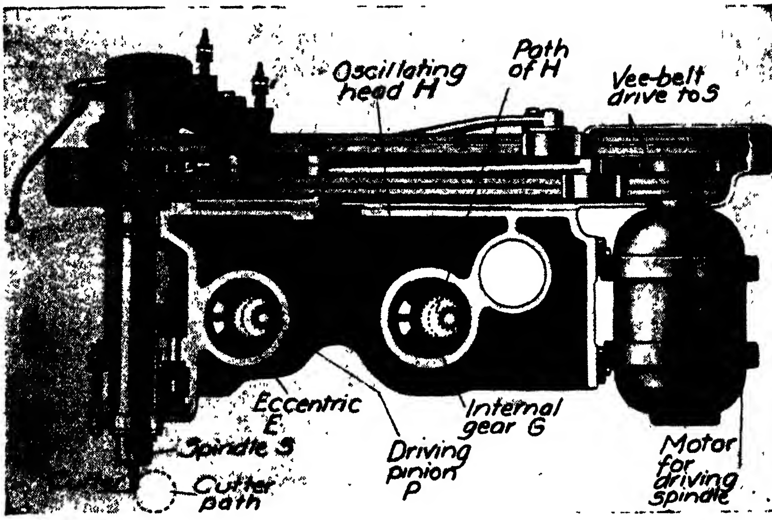

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FIG. 13-46. Section of Oscillating Head of Universal Die-sinking Machine.

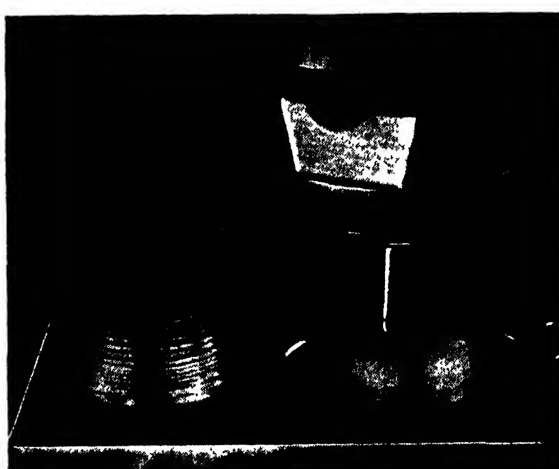

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FIG. 13-47. Cutting Hemispherical Surfaces on the Universal Die-sinker.

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FIG. 13-48. Die-sinking with a Taper Cutter.

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FIG. 13-49. Lead Cast Taken from Die Cavity.

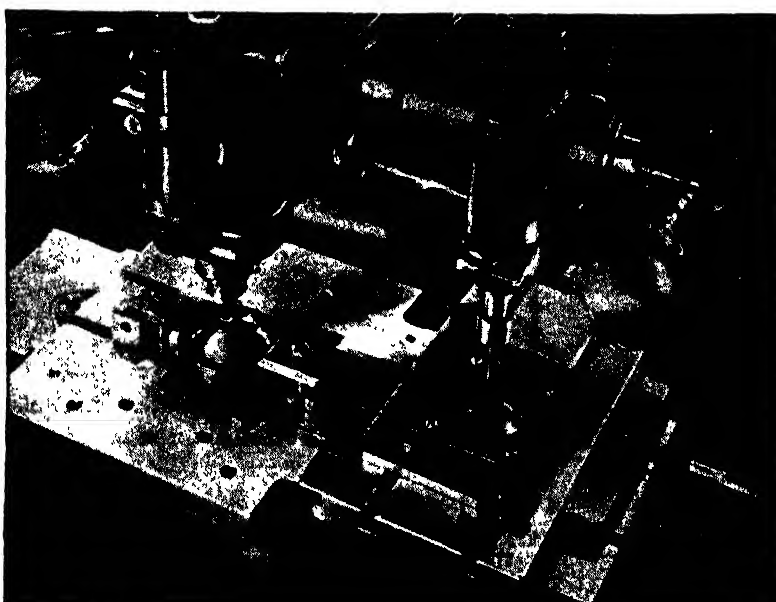

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FIG. 13-50. Die Duplicator or Profiler.

dicular to the table motion. The diameter of this path can be adjusted within limits of 3½″ and zero by changing the throw of the eccentrics *E*. The spindle *S* is driven by vee-belts and a vertical motor mounted on *H*.

The machine table in Fig. 13-45 has three tee-slots and numerous cross-slots for mounting the adjustable vise jaws shown. A rotary vise with a tilting top which may be rotated through 360° for accurate angular

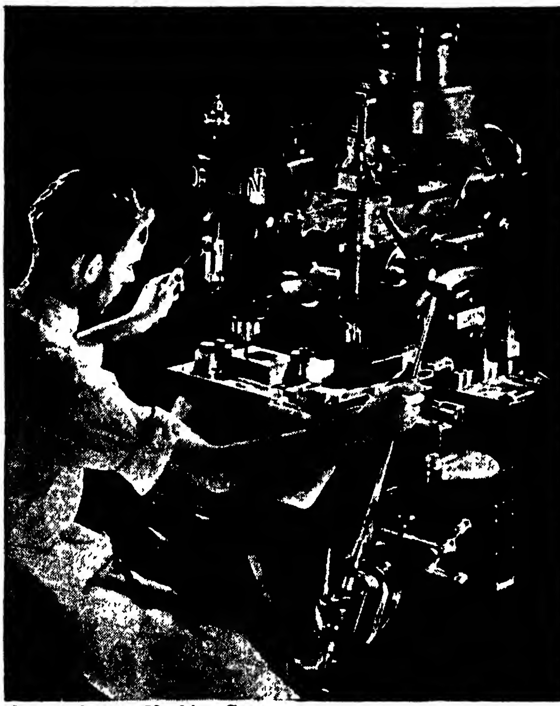

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FIG. 13-51. Operation of Die Duplicator.

positioning, or for circular work, can be mounted on the table. End milling cutters and burrs similar to those of Fig. 13-13 are used for most die-sinking operations.

Fig. 13-47 shows two steel hemispheres. The one at the left is roughed out, the other is finished to a 2½″ diameter. Roughing was done in one hour on the universal die-sinker by using the rotary table of the vise to feed the round-end cutting tool in a circle while the oscillating head moved the cutter from one position to the next. (The result of this operation is clearly shown by the tool marks on the left hemisphere.) Finishing required two hours, and was accomplished by using the oscillating head with a power

feed while the rotating table was used to shift the work from one position to the next.

Fig. 13-48 shows a die cavity 3⅜" long and 2½" maximum diameter, and Fig. 13-49 shows the lead cast that was taken by pouring molten lead into the machined cavity. The entire cavity was completely cut in about four hours on the die-sinker, and required only a few minutes final polishing to finish the die. The necessary forging draft was obtained by using a taper cutter.

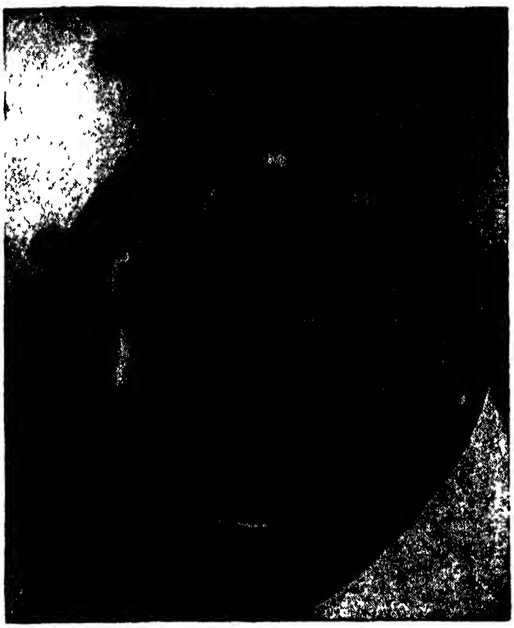

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FIG. 13-52. Bottom Plate for Glass Mold.

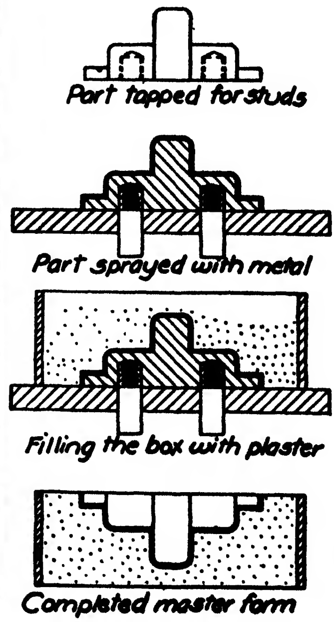

FIG. 13-53. Making a Master Mold for Duplicator Die-sinking.

Tal - Ron

176. The profiler is a vertical milling machine with two spindles, one of which carries a *tracer* or guide point, and the other an end mill whose cutting end is a *duplicate* of the tracer end. The operator follows a master template with the tracer and the end mill cuts a similar contour in the work Fig. 13-51 shows a modern high-speed profiling machine or duplicator. This machine has a table, saddle, and knee, for motion in three planes, and can be used as a vertical milling machine. A **duplicator unit,** which consists of a base that is bolted to the machine table and a duplicator table that is supported by ball bearing slides and is free to move on the base, is mounted on the machine table. The duplicator table can move freely in

any direction in a horizontal plane, and its motion is controlled by a hand lever at the right of the machine. A **master table,** on which the master die or form to be duplicated or reproduced is clamped, is mounted on the right end of the duplicator table, and is provided with two built-in micrometer heads so that the master form can be accurately set in relation to the spindles and the work.

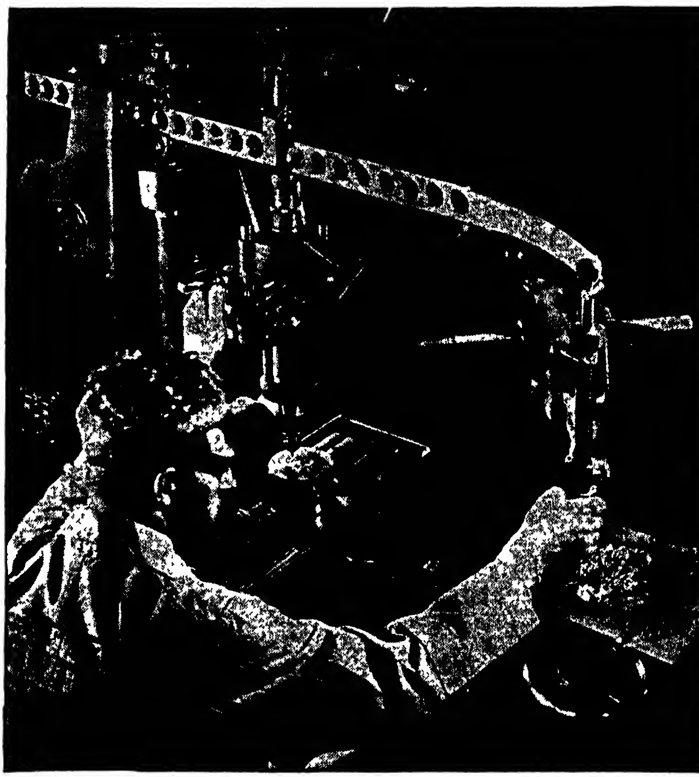

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Fig. 13-54. Three-dimensional Pantograph Duplicator.

The cutter spindle is at the left, and the tracer spindle at the right of the machine. The vertical feed of both spindles is controlled by a single hand lever at the left. In operation, the spindles feed downward, and the table moves in a horizontal plane as illustrated in Fig. 13-51. The tracer end limits the depth or distance that can be cut by the end mill or burr.

Fig. 13-52 shows the bottom plate for a glass mold, as received, without polishing, from the duplicator. The duplicating operation is illustrated in Fig. 13-50. The operator in Fig. 13-51 is machining a die for the bakelite

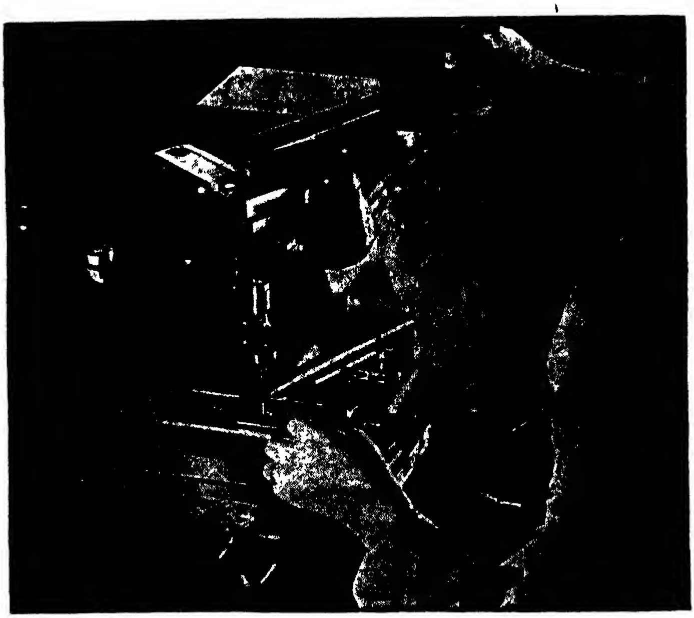

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FIG 13-55. Engraving the Lord's Prayer on a Two-dimensional Pantograph Duplicator.

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FIG. 13-56. Actual Photomicrograph of the Lord's Prayer Engraving Enlarged 400 Times.

body of a hair clipper mold. Work of this character requires a master mold or form, which in many instances may require many hours of careful die-sinking to make. Fig. 13-53 shows how a **master mold** may be fabricated directly from the object which is to be made in the die. The object used as an example is the half cylinder of Fig. 13-49. The part is drilled and tapped for two studs and placed on a plate through which the studs project. The outer surface of the part is metal-sprayed, and a sheet steel box is placed in position and filled with plaster or a similar substance. The entire unit is then inverted, and the box and part removed from the plate in a press by pushing on the stud ends. The object is then drawn out of the metal shell and box, leaving the master form.

177. Pantograph duplicators are used for simultaneous reproduction and size reduction. They are used for small, intricate designs that must be reproduced from models or patterns larger than the work in order to obtain the desired detail. Pantograph duplicators are made in two types: **two-dimensional machines** for engraving or shallow cuts on flat or uniformly-curved surfaces, and **three-dimensional machines** for die work. Fig. 13-54 shows a three-dimensional pantograph reproducing a medallion die. The master form and tracer are shown at the right, the cutter and the work at the left.

Fig. 13-55 shows a very interesting example of the possibilities of a two-dimensional pantograph. The operator is engaged in engraving the Lord's Prayer within a .005″ diameter circle on the end of a section of platinum gold wire. The pantograph reduction is 400:1; each individual letter is .0002″ high and is cut less than .000025″ deep. The accuracy and delicacy of the operation can best be appreciated if it is remembered that the photomicrograph shown in Fig. 13-56 represents a circle which is one-fourteenth the diameter of the head of a common pin.

CHAPTER 14

SURFACE FINISHING PROCESSES

178. Surface refinement and finishing processes for machined surfaces may be classified in two groups: those employing hardened steel tools, such as burnishing, scraping and filing; and those employing abrasives, such as grinding, honing, lapping, superfinishing and polishing.

179. Grinding is the process of removing metal by the use of solid or sectional abrasive wheels which rotate at a comparatively high speed. Originally employed for sharpening tools and for grinding casting fins, it later became an accurate tool room process. It is now extensively used in manufacturing processes, particularly in the mass production of precision parts. Parts that require hardening and tempering are generally finished by grinding so that distortion due to hardening can be eliminated. If the abrasive has been properly selected, very little cutting pressure is required for grinding, and the process may therefore be used in preference to cutting, if the work is fragile or if complicated in shape. Iron and steel castings are often more economically ground than machined, since the scale on the surface of the casting does not affect the abrasive wheel in the same manner as it does the edge of the cutting tool.

There are two kinds of **abrasives**, natural and artificial. **Corundum**, which is composed of about 85% aluminum oxide and 15% iron oxide, and **emery**, which is composed of 60% aluminum oxide and 40% iron oxide, are the principal **~~natural abrasives~~**. The relative abrasive action of each substance depends upon the proportion of aluminum oxide. The principal artificial abrasives are silicon carbide and synthetic alumium oxide. **Silicon carbide** is made in the electric furnace from coke and pure silica sand, with a little sawdust added to facilitate the reduction process. **Aluminum oxide** is made in the electric furnace from bauxite, a clay mined in Arkansas. Crystolon and Carborundum are trade names for silicon carbide abrasives; Alundun, Aloxite, and Borolon are trade names for aluminum oxide abrasives.

180. A **grinding wheel** consists of **abrasive grains** held together by some form of bond such as clay, shellac, or rubber. The hardness of the abrasive, the shape and form of the grain fracture, and the tenacity of the bond are each important in grinding operations. Natural abrasives are tougher than artificial but are not as hard. Artificial abrasives break with a sharp, clean fracture, and thereby present new cutting edges to the work.

If an abrasive does not *break out* readily, its edges become dulled and do not cut. If the bond is too soft, it permits the abrasive particles to tear loose too readily, and results in rapid wheel wear. If the bond is too hard, however, the abrasive particles will not tear loose when they become dulled, and the grinding wheel soon becomes loaded with particles which serve only to generate heat.

There are five **types of grinding wheels**, classified according to the bond employed. About 75% of all wheels are made by the vitrified process from ingredients which, upon proper heat treatment, are converted into glass which connects adjacent grains of abrasive. **Vitrified wheels** are made by melting clay or flint and abrasive material and water in a power operated mixer. The mixture is poured into molds and vitrified by burning at a high temperature for several days. After leaving the kiln the wheels are mounted in lathes and trued to dimensions, using a hardened steel conical cutter. The arbor hole in the wheel is bushed with lead or babbitt, and is trued in relation to the sides of the wheel. The wheel is graded for hardness, balanced, tested at a speed 50% greater than the normal operating speed, and carefully inspected for cracks, chipped places, and blowholes. Vitrified wheels are generally limited to surface speeds of 6500 feet per minute or less, but on account of their porosity and strength of bond, are used for both rapid material removal and precision grinding where finish and accuracy are important.

Silicate wheels are made of a mixture of silicate of soda and abrasive material which is tamped in a mold, dried, and baked at a temperature of 500° F. for from 20 to 80 hours. This bond releases the abrasive more readily than the vitrified type, and is therefore used where the heat generated in grinding must be kept at a minimum, as in tool grinding. Silicate bond is used in making very large solid wheels, for practical manufacturing reasons.

Shellac bond wheels are made of abrasive particles and shellac. The mixture is pressed into steel molds, placed in sand, and baked for a few hours at 300° F. Shellac wheels are capable of producing high finishes on such parts as cam shafts and mill rolls, and are also used for saw and knife sharpening in the woodworking industries.

Vulcanite wheels are composed of a mixture of abrasive grain and rubber, with sulphur added as a vulcanizer. The material is passed through mixing rolls and is then calendered to the proper thickness. The wheels are cut out of the sheet form by dies and heated under pressure in molds to vulcanize the rubber. Rubber wheels are used for high speed grinding and rapid stock removal. They are particularly efficacious for cutting-off, since the wheel may be made sufficiently thin to reduce the loss of material in cutting-off operations to a minimum.

Resinoid bond wheels consist of powdered synthetic resin, abrasive particles and a plasticiser, which are mixed and molded cold and baked at 320° F. for several days. This bond is used for the majority of high speed wheels in foundries and billet shops. Resinoid wheels are designed to operate at speeds up to 9500 feet per minute, and the rate of stock removal is generally in direct proportion to the speed.

The **grain** of an abrasive denotes its size, which is designated by a number that represents the size of mesh, per inch of length, that the abrasive particles will pass through. *Abrasives* from 4 to 240, and *flours* from 280 to 600, have been standardized in twenty-eight sizes by the Department of Commerce of the United States Government. An abrasive of grain size 36, for instance, will pass through a mesh with 36 holes per linear inch, but will not pass through a mesh with 46 holes per inch (the next smaller size).

The **grade** of a grinding wheel denotes its hardness, which cannot be accurately determined by the calcining or the mixture. Grading is usually done by hand and requires skill and experience. The grading is performed by pressing a tool, resembling a short steel screwdriver, into the side of the wheel and twisting it slightly. The resistance offered by the wheel is compared with the resistance offered by a wheel of known grade and indicates the hardness or grade of the wheel tested. A mechanical method which uses the hand principle is employed to some extent. Grade is often indicated by letters, running from *E*—soft, *I*—medium soft, *M*—medium, *Q*—medium hard, *U*—hard, and *Z*—extremely hard.

181. The **selection** of a suitable grinding wheel depends primarily upon the kind of material to be ground, but also ~~on the amount~~ of material ~~removed, the accuracy and finish required, the area of contact between~~ the work ~~and the wheel, and the type of grinding machine used.~~

Aluminum oxide wheels are generally used for materials of high tensile strength where the material is neither very brittle nor easily penetrated, such as carbon, alloy and high-speed steels, and wrought iron and tough bronzes. **Silicon carbide wheels** are employed for materials of low tensile strength, such as soft brasses, aluminum, glass and marble, and also on such easily penetrated materials as wood and leather. In general, hard, dense materials require a relatively soft grade of wheel; hard, brittle materials require fine grain or closely-spaced abrasives; very hard materials such as tungsten-carbide require widely-spaced abrasive wheels to permit rapid release of worn abrasive particles, since the material ground is almost as hard as the abrasive.

Hardened work and rough-turned or rough-machined work must have some **allowance for grinding.** The allowance should be as small as

possible so that the minimum possible amount of material is removed by grinding; on the other hand, enough stock must be left so that the work will be accurate at the conclusion of the grinding operation. No definite statement regarding the amount of grinding allowance can be made to fit all cases because the allowance depends upon such diverse factors as size, shape, and heat-treatment. One manufacturer, for instance, recommends the following as finish allowance for cylindrical work that is ground after rough-turning: .010″ for a piece ½″ diameter and 3″ long, varying to .030″ for a piece 12″ diameter and 48″ long. Closely-spaced, fine abrasive wheels generally give better finishes than coarse-grained, widely-spaced abrasives.

Silicate and vitrified wheels are generally operated at **cutting speeds** of from 5000 to 7000 feet per minute. Elastic bond wheels, such as shellac, vulcanite or resinoid, are usually operated at much higher speeds, sometimes as high as 16,000 feet per minute surface speed. An increase of wheel speed in grinding results in a larger number of individual abrasive cuts per minute, although each grain removes the same quantity of material.

In cylindrical grinding, **work speeds** of from 40 to 50 feet per minute are used for cast iron and machinery steel parts from 1″ to 3″ in diameter. Work speeds up to 200 feet per minute are sometimes used for large work, but are impracticable for very small work because of vibration. Really good finishes require far slower work speeds. An increase of work speed in grinding results in an increase in the grain depth of cut, since each grain must remove more material from the work in the same number of cuts per minute.

The area of contact between the work and the wheel influences the selection of grain and grade. Soft wheels are generally used for grinding large diameter work and plane surfaces; harder-bonded wheels are used for small diameter work and wheels. In using a wheel which grinds on its periphery only, a change in the width of the surface contact has no effect on the grade. In grinding plane surfaces with the face of a wheel, however, the contact area is so great in comparison to peripheral grinding that the wheel must generally be much softer than a similar peripheral wheel.

Grinding wheels can be obtained in a variety of **shapes** and sizes. A few of the stock varieties are illustrated in Fig. 14-1. The straight wheel *A* and the recessed straight wheel *D* are generally used on precision grinding machinery for peripheral grinding. The straight cup wheel *E*, the cylinder wheel *F*, and the dished wheel *G* are used for face grinding. (The symbol *C* indicates the cutting surface of the wheel.) The taper-sided wheel *B* is used in bench grinders and applications where dished flanges can be used. *L, M,* and *N* illustrate three standard grinding wheel face shapes (other

than straight). *L* is often used for thread grinding; *M* and *N* for concave and convex surfaces, ball and recess grinding, and like applications. *H, J,* and *K* illustrate three of the many types of mounted grinding points. These wheels are made with integral steel shanks to fit spindles or chucks of portable grinders for die finishing and other hand operations.

Although properly selected grinding wheels should be self-sharpening, they must occasionally be dressed or trued to remove dull grains of abrasive

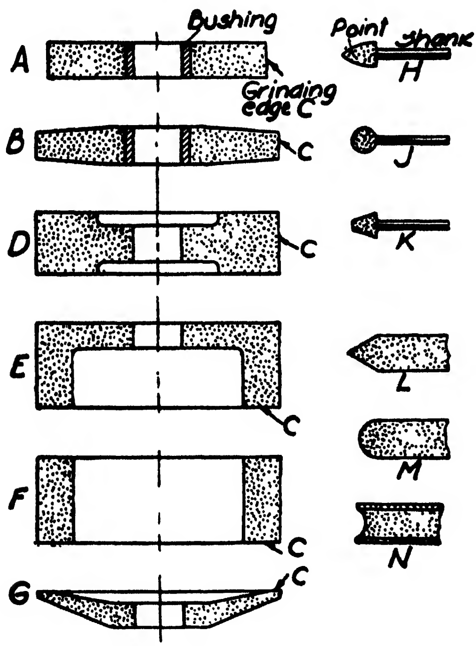


FIG. 14-1. Grinding Wheel Shapes and Types.

FIG. 14-2. Mounted Diamonds for Truing Grinding Wheels.

and metal particles, and to restore the original shape and accuracy of the wheel face, especially in precision grinding. **Dressing** may be done by using a dressing tool which consists of a series of hardened "star" wheels free to rotate in a hand holder. **Truing** is generally done by using **mounted diamonds**, several varieties of which are shown in Fig. 14-2. Most of the diamonds used for abrasive wheel truing are either of the bort or ballas variety. Fig. 14-2 *B* shows a stone mounted with a screw cap; *C* shows the usual commercial mounting in which stones are imbedded in a matrix and peened in place; the holder shown has several diamonds in

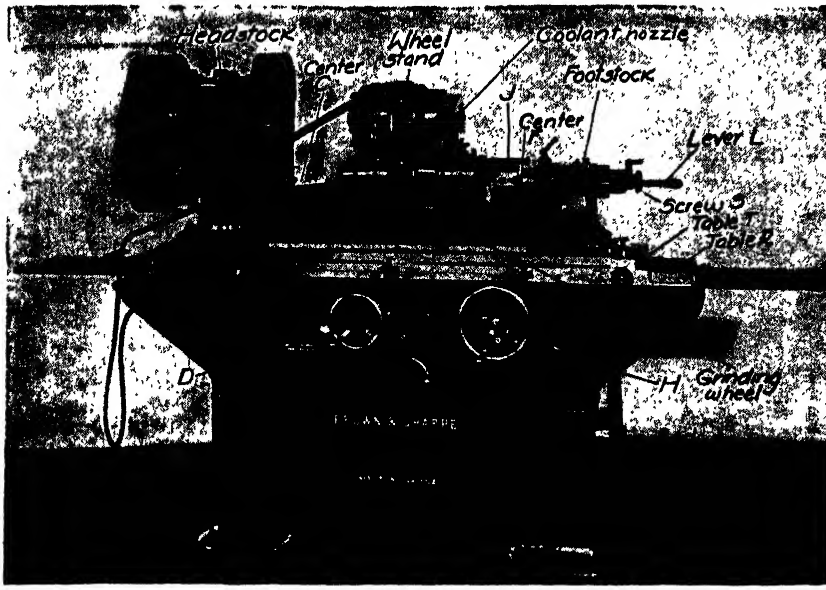
tandem so that a new stone can be made available by grinding back the holder. Fig. 14-2 *A,* shows a truing tool with a point ¼″ in diameter, which is composed of many small diamonds imbedded in a tungsten-carbide matrix. The point is brazed to a short steel shank which is inserted in the end of a holding rod for hand or machine use. Three grades—fine, medium, and coarse diamond particles—are furnished for various conditions of service. Bench grinder wheels may be dressed by hand, but precision grinder wheels are trued by supporting the diamond and its holder in special fixtures or attachments so that an accurate profile may be obtained.

182. Precision grinding machinery for unit-production processes may be divided into two classes, cylindrical grinders and plane surface grinders. Fig. 14-3 illustrates a modern **universal grinding machine** that is used for grinding internal and external cylindrical and conical surfaces. The lower table *R* is free to move from left to right on the ways or guides on the bed, and carries a swivel table *T* on which the headstock and footstock are mounted. *T* can be adjusted on *R* so that tapers up to 3½″ per foot can be ground. Fig. 14-4 illustrates the principle of operation of the **headstock.** The pulley *P* on the headstock spindle nose is used for driving the work while the spindle is stationary; in contrast to lathe work, grinding between centers is done with both headstock and footstock centers *C* and *F* stationary. The headstock spindle is adapted to chuck mounting by removing sleeve *B,* which permits the chuck to be screwed on the spindle nose. When the spindle rotates, the rear pulley drives, and the stop pin *R* is retracted.

The **footstock** is similar to a lathe tailstock with a sleeve operated by a spring-actuated lever *L,* to provide a uniform work pressure and to facilitate removal and replacement of the work. A screw *S,* however, is available for heavy work that must be positively supported.

The **wheel stand** carries an individual motor for driving the grinding wheel spindle by three parallel vee-belts. In this machine, the grinding wheel is shown between the bearings, but it can be mounted on either end of the spindle if required for special operations. The platen on which the wheel head is carried is swivel-mounted on a slide which is in turn swivel-mounted on the bed of the machine. An **internal grinding fixture** is mounted at the rear of the wheel head so that the spindle *J* can be brought into operating position by rotating the wheel head platen 180°. The internal grinding spindle *J* is also driven from the wheel stand motor. The machine has three spindle speeds and six work speeds available.

The table has ten rates of longitudinal power travel speed, ranging from 3″ to 60″ per minute. The table may be hand operated by turning handwheel *H.* The table is provided with adjustable trips so that its travel may be



Brown & Sharpe Mfg. Co.

FIG. 14-3. Motor-driven Universal Grinding Machine.

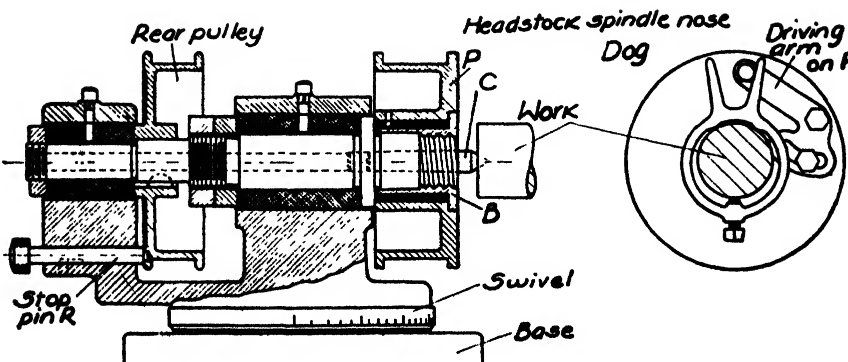


FIG. 14-4. Work Head for Universal Grinder.

closely controlled. Handwheel *D* actuates the manual cross-feed of the wheel stand for setting the wheel for depth of cut. An automatic cross feed can be set to feed from .00025″ to .004″ on the diameter of the work at each reversal of the table. The feed can also be set to vary the amount of feed at the end of each stroke.

183. Fig. 14-5 illustrates some **representative operations** that may be performed on the grinder of Fig. 14-3. Operation *A* shows how a cylindrical surface ending at a shoulder is ground; the corner should have a *grinding neck* or recess, as indicated, to eliminate the possibility of the edge of the wheel touching the shoulder. The longitudinal movement of the work or **work traverse,** indicated by *WT,* should equal nearly the entire width of the wheel during each revolution of the work. In most cases the maximum production will be obtained by using the widest possible wheel. If the wheel face is slightly wider than the length to be ground, the work need not be traversed at all. This method of grinding is known as **plunge-cut grinding** and may be used for cuts up to 9″ wide, provided the work is stiff enough or is suitably supported. Plunge-cut form grinding is illustrated in operation *C,* Fig. 14-5, and is effected by the cross travel *ST* of the spindle and wheel stand. This operation is also illustrated in Fig. 14-6 which shows the work carried on a mandrel supported by dead centers and driven by a dog.

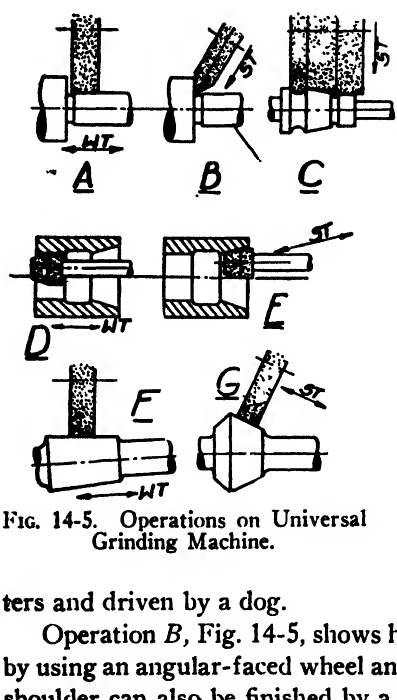
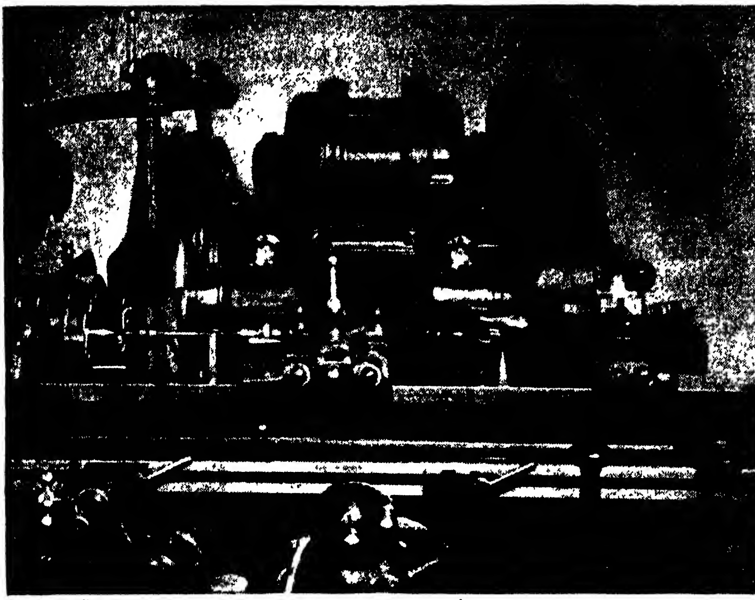


Fig. 14-5. Operations on Universal Grinding Machine.

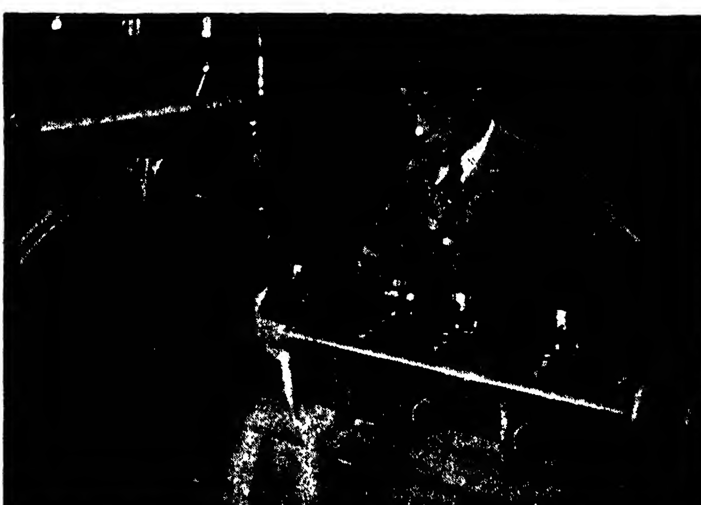
Operation *B,* Fig. 14-5, shows how a shoulder may be accurately finished by using an angular-faced wheel and the cross-feed of the wheel stand. The shoulder can also be finished by a straight or a cup wheel feeding perpendicular to the spindle. Operations *F* and *G* show two methods of **grinding external tapers**; in *F* the table is set over at the proper angle, while in *G* the taper is ground by the movement of the wheel stand slide.

Operations *D* and *E,* Fig. 14-5, illustrate how a straight hole and a tapered seat may be ground at one setting of the machine. The wheel stand slide is set at an angle parallel to the sides of the tapered hole. Operation *D* is performed by using the table traverse, and operation *E* by using the hand cross feed of the wheel stand for grinding the taper hole.



Norton Company

Fig. 14-6. Form Grinding Work That Is Supported on Centers and Driven by a Dog.



Norton Company

Fig. 14-7. Grinding a Cylindrical Shaft Supported Between Centers and by Four Steadyrests.

Long slender work should be supported by steadyrests or backrests as illustrated in Fig. 14-7. Except for tool grinding, a **coolant** is generally used for grinding operations in order to keep the work at a constant temperature. While plain water will serve as both lubricant and coolant, various compounds such as oil and soda are usually added to assist in lubrication and cooling and to prevent rusting of the machine and the work.

184. There are two forms of **internal grinding.** In the first, the work is rotated and held in a chuck or is mounted on a faceplate; in the second, which is illustrated at *C* and *D,* Fig. 14-9, the work is mounted on

Norton Company

FIG. 14-8. Internal Grinding of Roller Bearing Cages.

the table of the machine and travels toward and from the wheel, which not only rotates about its own axis, but also travels in a circular path whose diameter is equal to the diameter of the hole to be ground minus the diameter of the grinding wheel. The second form is known as **planetary grinding** and is used for work that cannot be conveniently rotated, such as bore regrinding operations on cylinder blocks.

Internal grinding wheels are generally used until completely worn out, and are therefore usually purchased as large as possible in order to economize on wheel cost. A large wheel will, however, have a much longer arc of contact than a small wheel, and a much softer wheel must be used than if the wheel is small in relation to the diameter of the hole. If the hole has a keyseat or slot in it, as illustrated at *B,* Fig. 14-9, a hard wide-faced wheel

should be used since the keyseat edge has a shaving action on the face, tends to tear out the grains quickly, and reduces the life of the wheel.

In finishing work that is ground on both the exterior and interior cylindrical surfaces, it is generally advisable to grind first the bore and then finish the exterior by mounting the work on a mandrel. It is generally easier to grind the outer surface concentric with the bore, than to try to align a part in a chuck so that the exterior is concentric with the spindle axis.

185. The machine shown in Fig. 14-3 is also used for **grinding cutters** and reamers which are generally held on an arbor supported between centers. Fig. 14-10 shows two methods of grinding the teeth of profile-type milling cutters. In method *C* the grinding wheel rotates from the body of the tool off the cutting edge. The rotation of the wheel holds the cutter on the tool rest, but the wheel action has a tendency to draw the temper

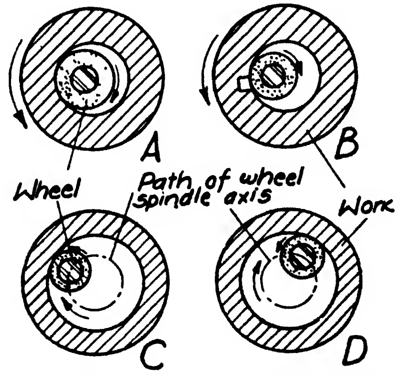


Fig. 14-9. Internal Grinding Principles.

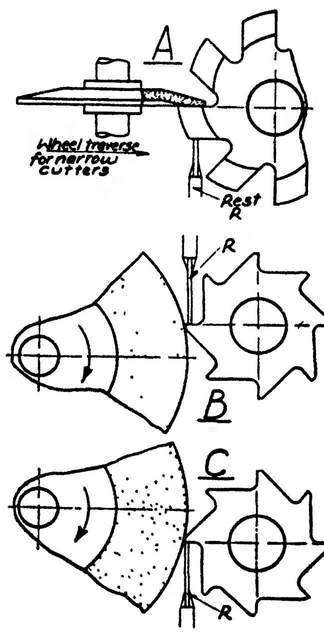


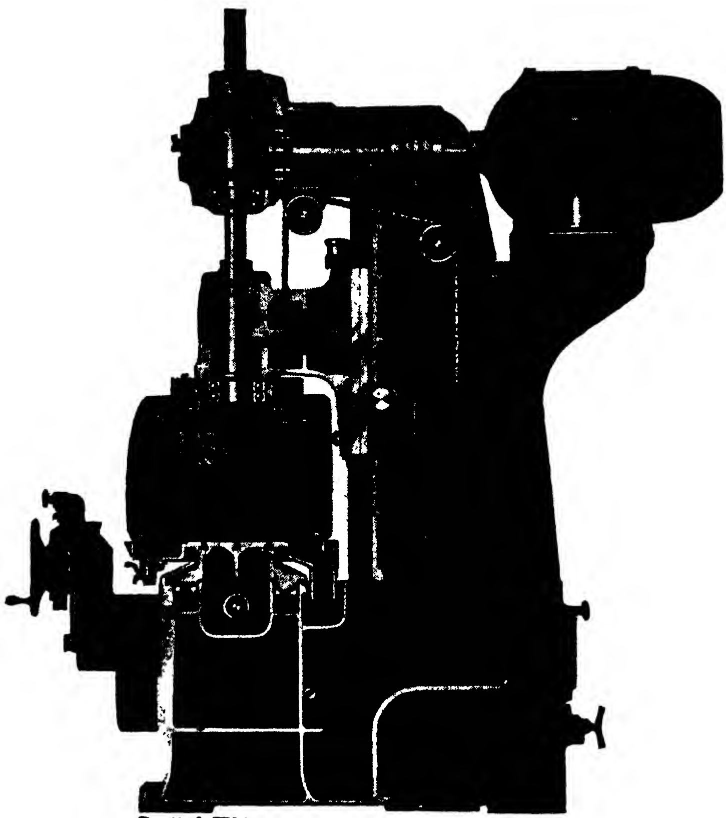
Fig. 14-10. Cutter Grinding Principles.

of the steel, and raises a burr on the cutting edge, which must be removed by stoning. In method *B* the wheel rotates from the cutting edge to the body of the tool, and results in less danger of burning the tooth. Great care, however, must be exercised to hold the cutter on the tooth rest, since the rotation of the wheel tends to turn the cutter away from the rest. If the cutter turns while grinding, a ruined tooth or a cracked wheel will result.

Fig. 14-10 also shows how form-type cutters are ground using a dished wheel. Narrow cutters are ground by traversing the wheel radially, as illustrated, but cutters of appreciable width are generally sharpened by

moving the wheel parallel to the cutter axis. In all types of cutter grinding, great care is taken to grind the same amount from each tooth, or else one or more teeth may do all the cutting when the tool is used.

186. Surface ~~grinding is the term used to describe the~~ operation of producing plane surfaces by grinding. Two types of surface grinding



Pratt & Whitney

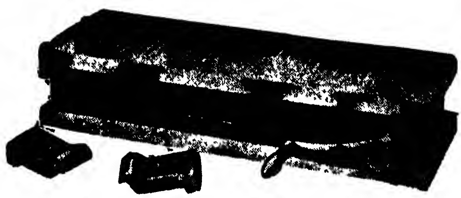
Fig. 14-11. Surface Grinder.

machines are used: planer type machines in which the work table has a rectilinear reciprocating movement; and rotary type ~~machines in which the~~ work table rotates. Each type is made in vertical and horizontal spindle sub-types.

Fig. 14-11 shows a sectional view of a **vertical spindle surface grinder** with a reciprocating work table. The spindle is driven by a 30-hp. motor through a flexible coupling and a pair of spiral bevel gears,

and rotates in ball bearings in a wheel head which moves vertically on the column of the machine. The automatic down feed mechanism for the wheel is effected by a ratchet and pawl actuated by a hydraulic cylinder, and can be varied between limits of .00025" and .005" for each table stroke. The down feed can also be operated by hand. The entire wheel head is counterweighted. The illustration shows a 14" cylindrical wheel, although a 17" segmental wheel can be used if desired. The table is driven hydraulically by a 5-hp. motor and pump, with table speeds between 2 and 100 feet per minute. Automatic table reversing takes place at any point and is regulated by adjustable dogs. A separate dog positions the table for wheel truing. A tank in the base of the machine, as illustrated, contains the coolant which is supplied to both the inside and the outside of the wheel by a built-in pump.

187. Work can be clamped to the tables of surface grinders but magnetic chucks are commonly used. Two types of magnetic chucks are used for this purpose: the permanent-magnet type of chuck, and the electrified chuck. Fig. 14-12 illustrates a rectangular permanent-magnet type chuck and Fig. 14-13 shows the operating principle of this device. The chuck consists of an upper platen and a lower base, held in a frame, between which there is a movable plate consisting of alternate permanent magnets and iron conductors of high permeability separated by non-magnetic strips. The plate is shifted laterally by a crank shown in Fig. 14-12. When the handle is turned to the "on" position, the separators are aligned so that the magnetic flux flows through the face of the chuck and the work, following the path of least resistance and thereby holding the work to the face of the chuck. When the handle is turned to the "off"



Brown & Sharpe Mfg. Co.

FIG. 14-12. Permanent-magnet Type Chuck, Rectangular Model.

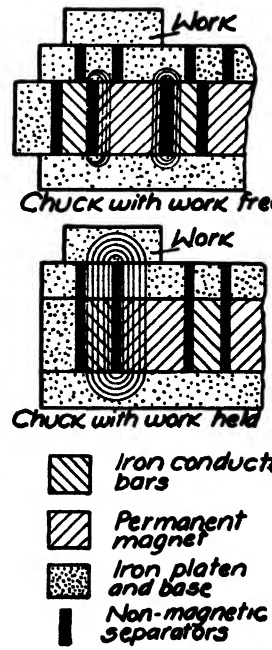
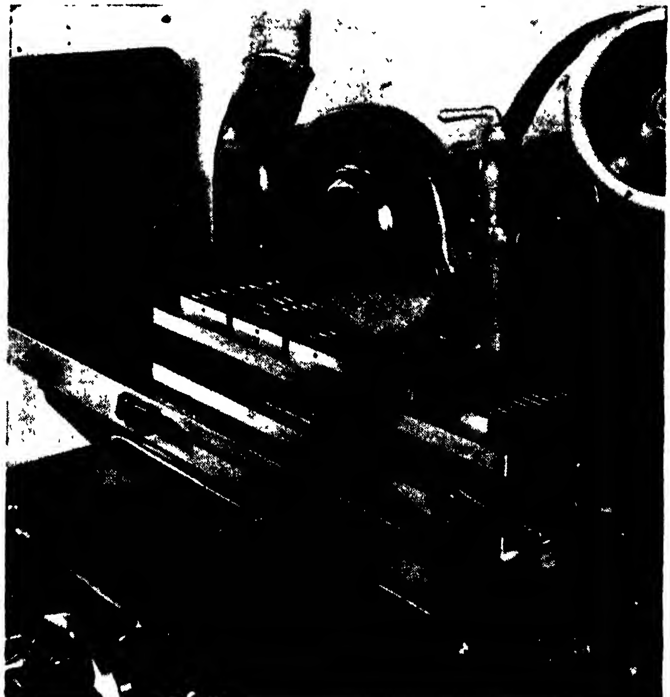


FIG. 14-13. Operation of Magnetic Chuck.



Brown & Sharpe Mfg. Co.

FIG. 14-14. Surface Grinding, Using a Permanent Magnet Type Chuck

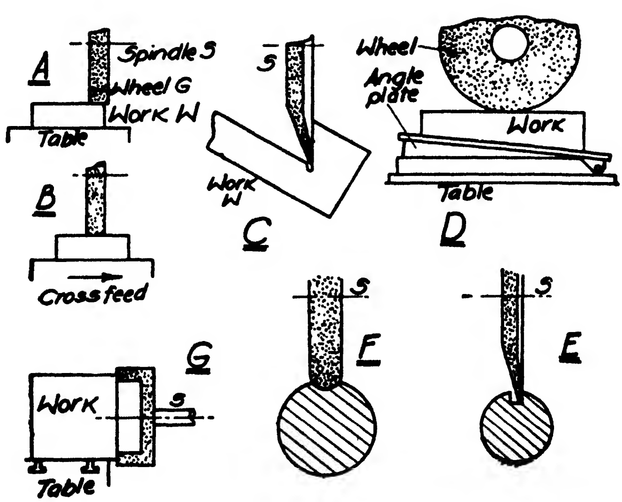
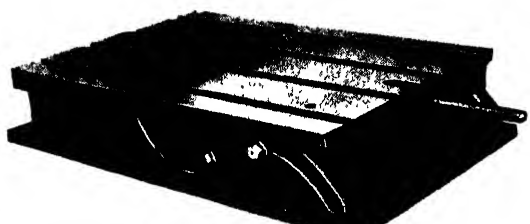


FIG. 14-15. Operations on a Planer Type Grinder with a Horizontal Spindle.

position, the separators are shifted so that the flux takes the shortest path, passing through the face of the chuck without going through the work, thereby leaving the work free.

Electrified magnetic chucks are equipped with magnets which are energiz~~ed by a coil through which direct current flows. Ele~~ctrified chucks are built ~~in larger sizes than permanent-magnet chucks and are m~~ore powerful, but the permanent-magnet type requires no current, and there is no danger of the work being accidentally released or thrown off on account of pow~~er failure. Both types of chucks~~ are made in either rectangular or rotary models, one of which is shown in Fig. 14-14 and another in Fig. 11-11.

Fig. 14-14 shows a planer type table **surface-grinder with a horizontal spindle** on which a straight wheel, which grinds on its periphery, is used. This type of machine is extensively used for tool room and other forms of unit-production operations on account of its flexibility and adaptability. The table of the machine is mounted on a saddle for cross-feeding, since successive cuts at the same setting are necessary to finish wide-surfaced work. The spindle is carried in bearings in a wheel head which is adjusted vertically on the machine column. The depth of cut or the amount removed at one pass of the table is adjusted by a graduated handwheel at the top of the column.



Cleveland Universal Jig Co.

Fig. 14-16. Adjustable Angle Plate.

Fig. 14-15 shows several **representative surface grinding operations.** *A* and *B* illustrate two stages in grinding a flat surface, showing the cross-feed of the saddle as the table reciprocates. This operation is also illustrated in Fig. 14-14 which shows a number of parts held on a permanent-magnet type chuck. Fig. 14-15 *C* shows how the side of a dovetail slide may be ground with a dished wheel. In this operation the spindle head is hand fed in a vertical direction and the saddle of the machine is locked in place for each depth of cut. The work may be held in an adjustable swivel vise or clamped to the surface of an angle plate similar to Fig. 14-16. This plate is adjustable from 0° to 48° with the horizontal, and can be set for any angle within its range by using gage blocks or a micrometer between measuring points in the base and top of the fixture. Fig. 14-15 *D* shows the application of this angle plate in grinding tapered gibs for plain slides. Operations *F* and *E* illustrate how grooves or slots in cylindrical work may be ground. The work may be held in a vise, set up on vee-blocks, or sup-

ported between plain index centers. Fig. 14-15 *G* shows a third variety of planer type grinding machine which has a horizontal reciprocating table and a horizontal wheel spindle. This machine uses the rim of a cylinder or cup wheel, and is principally employed in mass-production operations for surfacing medium and large sized castings and other parts.

Surface grinding machines with **rotary tables** are illustrated in Fig. 14-17 and 14-18. Fig. 14-17 shows a grinder which has a vertical spindle and a cylindrical wheel and uses the rim of the wheel. Fig. 14-18 has a horizontal spindle and uses the periphery of a straight wheel. Vertical spindle rotary grinders, as a rule, remove stock more rapidly than those machines that use the periphery of the wheel. The latter, however, will produce a surface consisting of concentric lines which can be sufficiently fine to give a perfect seal with a mating part or sufficiently coarse, although accurate, to hold gaskets or packing on steam pipe flanges and similar applications.

Norton Company

Fig. 14-17. Plane Surface Grinding on a Rotary Type Machine with a Vertical Spindle.

Large or small pieces can be ground singly, or the rotary table can be loaded with a large number of small pieces held on a rotary magnetic chuck between inner and outer rings of iron and steel slightly thinner than the work to be ground. The inner ring is used because it is often undesirable to load parts to the center of the table, since there is a great difference between work speeds near the center and at the edge. A grinding wheel that would give satisfactory performance at one point might not grind properly at other points. The rotary tables of some machines can be tilted to grind convex and concave, as well as flat surfaces. Other machines have a swivelling wheel head for special jobs.

188. Many rough and semi-precision surface grinding operations can be handled on disc grinders. **Disc grinders** are of three principal types: **horizontal spindle machines,** such as illustrated in Fig. 14-19, in which the work rests on the horizontal table and its vertical edge is ground; **vertical spindle machines** where the work rests on a horizontal abrasive disc and is held firmly in contact with the abrasive surface by its own weight or by hand; and special machines, such as a double-wheel machine where the work is fed between two wheels for grinding two surfaces simultaneously.

The original **disc wheel** consisted of a sheet of abrasive paper or cloth cemented to a steel disc wheel, and is still used in many instances. Other disc grinders use a solid abrasive wheel vulcanized to a steel plate which is in turn bolted to the disc on the machine. Disc grinding is used for *snagging* and rough-finishing castings, often replaces filing for *burring* flat surfaces, and is frequently employed for smoothing parts to secure a locating surface for subsequent operations. Where great accuracy is not required, disc grinding is usually less expensive than other surface grinding methods.

Norton Company

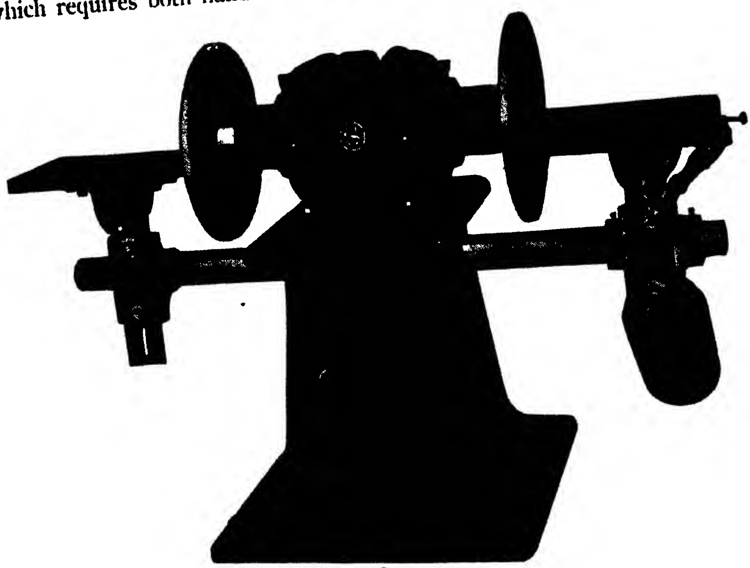
Fig. 14-18. Plane Surface Grinding on a Rotary Type Machine with a Horizontal Spindle.

189. Fig. 14-20 shows a motor-driven grinding attachment that may be mounted in the tool post of an engine lathe or a tool-room shaper. This attachment is employed in shops that do not have precision grinding machinery available, and is used for cylindrical and surface grinding.

190. Bench type and floor stand grinders are used for tool grinding and for miscellaneous hand operations. The grinder of Fig. 14-22 has a dry wheel at the left and a water-cooled wheel at the right. Some machines have adjustable tool rests so that cutting and relief angles on lathe and planer tools may be ground with a considerable degree of accuracy.

Portable grinders may be either electrically or pneumatically actuated, and are obtainable in a wide variety ranging from the pencil-type die

grinder shown in Fig. 14-26 to the portable grinder shown in Fig. 14-27, which requires both hands for operation.



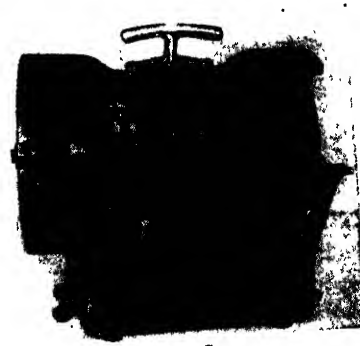
U. S. Electrical Tool Co.

Fig. 14-19. Disc Grinder.

191. When a cutting tool is sharpened, grinding often leaves a series of small points which terminate in a slight burr or wire edge. If the

U. S. Electrical Tool Co.

Fig. 14-20. Lathe Grinder.

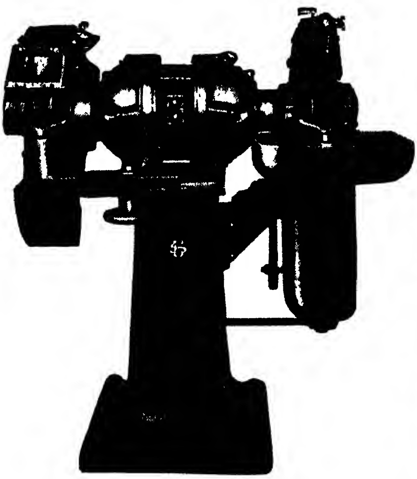


Black & Decker Mfg. Co.

Fig. 14-21. Ball-bearing Bench Grinder.

tool is used in this condition, it will leave tool marks on the work and the tool itself will not hold an edge for any length of time. This wire edge

should be removed by the proper use of an **oilstone.** Artificial oilstones use either aluminum oxide or silicon carbide as the abrasive, with a vitrified



U. S. Electrical Tool Co

FIG. 14-22. Combination Wet and Dry Grinder.

Norton Company

FIG. 14-23. Off-hand Grinding of a Large Forged Lathe Tool on a Floor Stand Grinder.

bond. They are obtainable in three classifications: coarse, medium, and fine, and can generally be purchased as combination stones as illustrated in

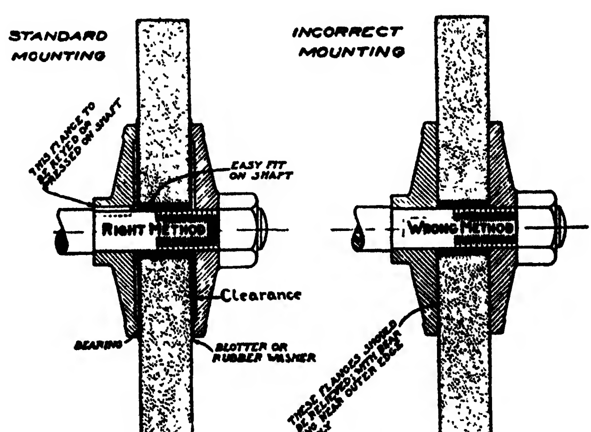


FIG. 14-24. Correct and Incorrect Methods of Mounting Grinding Wheels on Bench or Floor Stand Grinding Machine Spindles.

Fig. 14-28. Natural stones such as Washita, Soft Arkansas and Hard Arkansas are finer and denser than artificial stones, and range downward in

denseness to Hard Arkansas which is the finest of all oilstones. Natural stones are used for fine tools and instruments whenever the ultimate in fine edges is desired.

Photo by E. S. Miller, Jr.

FIG. 14-25. Grinding a Twist Drill.

Reamers, boring tools and milling cutter edges are improved by stoning, since such practice will result in better finish, closer tolerances, and longer tool life. Oilstones are also useful for die finishing

Norton Company

FIG. 14-26. Using a Mounted Point in a Pneumatic Portable Grinder.

and in fitting parts of precision instruments. Oilstones are made in a wide variety of shapes and sizes, such as cylindrical, conical, wedge-shaped, etc. They require the use of a light oil on their surface to float the minute particles of steel abraded from the work so that these par-

ticles will not become imbedded in the stone and eventually cause glazing.

W. A. Jones Foundry & Mach. Co.

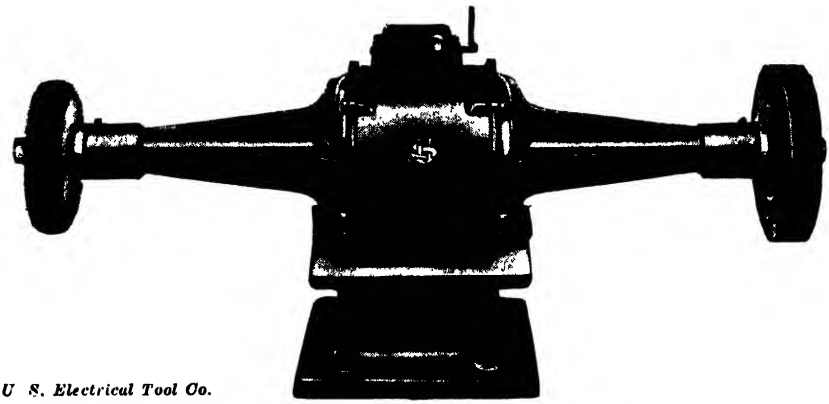
FIG. 14-27. Grinding the Teeth of a Cast Tooth Bevel Gear, Using a Portable Grinder.

Norton Company

FIG. 14-28. Sharpening a Wood Chisel on an Oilstone.

192. **Polishing** is a surface finishing process by which scratches and tool marks are removed with a polishing wheel. Polishing wheels are made

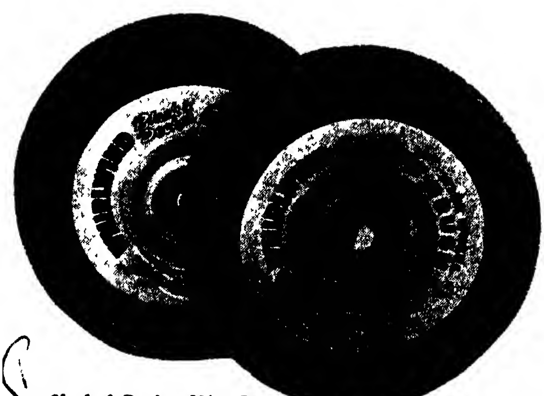
of canvas, leather, felt or paper, to the faces of which abrasive grains are glued or cemented. **Buffing** is a surface finishing process in which very little material is removed, since the sole purpose of the operation is to produce a lustrous surface of attractive appearance. Powdered abrasives are



U. S. Electrical Tool Co.

FIG. 14-29. Polishing and Buffing Machine.

usually applied to the surface of the wheel by pressing a stick or cake of abrasive against the wheel face and periodically replenishing the abrasive as it is removed by the contact of the work. Soft pliable materials such as felt, linen, or cotton, are used for buffing wheels.



Black & Decker Mfg Co.

FIG. 14-30. Wire Brush Wheels.

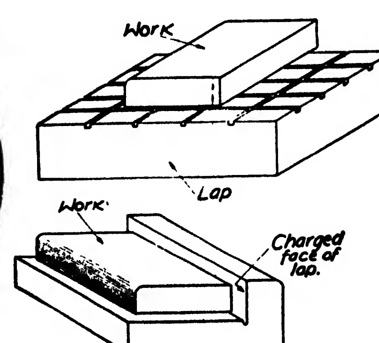


FIG. 14-31. Lapping Plane Surfaces.

Wire brush wheels are used for cleaning castings, removing scale and rust, and for producing "scratch-brush" finishes on non-ferrous materials. Wide-faced brushes are obtained by building up several narrow sections.

193. A wide variety of **coated abrasives** are employed in hand finishing operations. Coated abrasives consist of flexible sheets, such as paper or cloth, to which the abrasive is glued. **Emery cloth** and flint paper, or **sandpaper,** are familiar examples of coated abrasives. **Crocus cloth** is a fabric coated with ferrous oxide which is red in color and has a rather hard structure. **Rouge** is a red powder con-

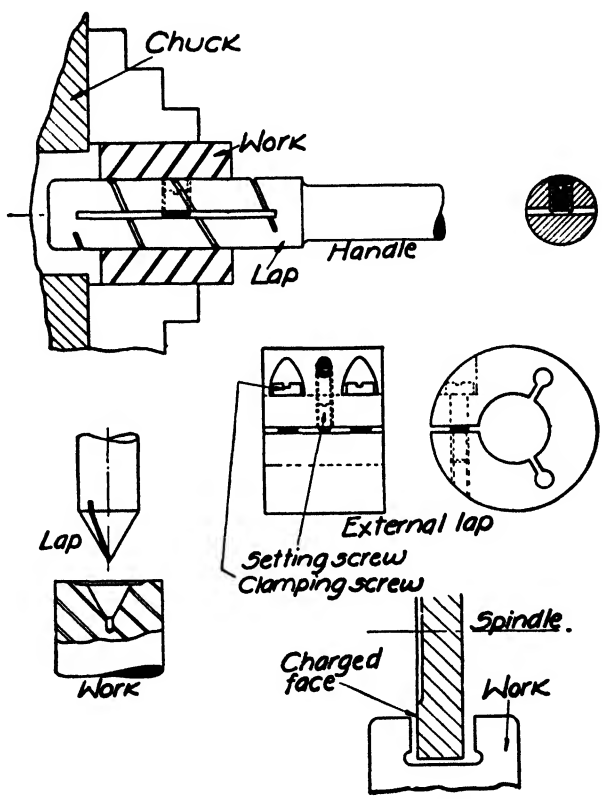


Fig. 14-32. Representative Lapping Operations.

sisting of ferric oxide. It is somewhat softer than crocus. Rouges containing aluminum oxide or chromium oxide and silica are also used. Coated abrasives are also available in **string form** for finishing and polishing eyelet and thread holes in textile machinery.

194. Lapping is the process of producing an extremely accurate, highly finished surface by means of a **lap,** which is a block charged with abrasive. Lapping reduces the possibility of wear on close-fitting running parts or on the surfaces of measuring equipment, by reducing the minute

ridges and serrations left by machining and grinding operations to a more uniform bearing surface.

Lapping may be done by hand or by machine. If a part is to be **hand lapped** to a final accurate dimension, a lap or mating form is made from a metal somewhat softer than the part to be finished. The surface of the lap is charged with a fine abrasive, or a small amount of abrasive mixed with grease, oil, or alcohol. Fig. 14-31 shows how one surface of a hardened steel part may be finished on a flat cast iron lap. The lap has a carefully-trued surface with a series of grooves in it. The lapping compound is smeared on the face of the lap and the work is rubbed over the face along an ever-changing path. The grooves in the face of the lap act as channels for any excess abrasive and oil. Very little pressure is used in order to eliminate the danger of scoring the work or stripping the lap. Hand lapping requires skill and time. The amount of material removed by lapping should not exceed .0002" to .0005".

Fig. 14-31 also illustrates a *squaring lap* in which the edge of the steel part is lapped at right angles to the bottom surface. In using this device the abrasive is spread along the vertical edge of the lap, and the horizontal surface is frequently wiped clean to prevent further lapping action on the surface that is already finished. Fig. 14-32 shows several other methods of lapping. The cylindrical lap, which is shown lapping a cast iron bushing held in a lathe chuck, is made of brass and is split and has a set screw so that the lap can be adjusted for wear. A helical groove of irregular lead in the surface of the lap serves as a channel for the abrasive and oil. Great care must be exercised to avoid bell-mouthed holes; in some instances, particularly in lapping ring gages, the part is made with some excess length so that any accidental enlargement of the ends of the hole may be eliminated by cutting off these portions. Ring laps are used for lapping cylindrical surfaces; the lap shown can be adjusted for size.

When work which is supported between centers is to be ground to close limits, the **center holes** are generally **lapped** prior to the grinding operation. The lapping operation may be performed in a drill press using a conical lap with one groove as illustrated. The center holes are carefully cleaned after lapping so that no abrasive remains to continue the process involuntarily while the work rotates on the grinding machine centers.

Fig. 14-32 also illustrates how snap gages may be lapped on a surface grinder or a milling machine. The wheel or cutter is removed and a cast iron disc is substituted. The finished surface of the disc is charged with diamond dust, which is applied by rolling it into the surface of the lap with a hardened steel roller. The work is held in a vise in the position illustrated. Diamond dust laps are also used for lapping cemented carbide tools to obtain a keen cutting edge.

CHAPTER 15

WELDING AND ALLIED PROCESSES

195. Soldering comprises the joining of two metal parts by a metal called solder, which consists of equal parts of lead and tin, whose melting point is lower than that of the metals to be joined. The process consists of cleaning the surfaces to be joined, heating them to the soldering temperature by any suitable means such as a soldering iron, a gas flame or a blow-pipe, and applying a flux, which is generally rosin or borax, for the purpose of removing any grease or oxide present. The solder is then melted into the joint and the joint smoothed over and finished by the use of a soldering iron.

Brazing is essentially similar to soldering, the principal difference being the use of a harder filling material called spelter, which is generally a mixture of copper, zinc, and tin. In brazing, the parts to be joined are carefully cleaned, the flux is applied, and the parts clamped in position for joining. The parts are carefully heated and the molten spelter is "flowed" by capillary action into the space between the parts and allowed to cool slowly.

Immersion brazing is used in large-scale production. The parts are cleaned and fluxed, clamped together, and then dipped into a tank of molten spelter.

Silver soldering is a form of low temperature brazing in which the solder may be a high percentage silver alloy. Silver soldering is used where greater joint strength than is possible with soft soldering is required.

Brazed joints are widely used in small applications, and represent reliable commercial practice. When well made, brazed joints may be as strong as the original metal. Soldered joint strength is limited to the strength of the solder which is almost always lower than that of the parent metals. Neither process is as effective as welding but soldered or brazed joints are much less expensive to make than welded joints.

196. The oldest form of **welding** is the **manual forge process.** All forms of plastic welding are mechanical processes, and require plastic flow of the materials to be welded as well as the wetting or cohesion of the two surfaces at welding heat. In blacksmith's forging, the plasticity is obtained by the heat of the forge and the metals are united by hammer blows. In welding steel bars, the material must be heated to a temperature of from 1400° F. to 2700° F., with the surfaces properly shaped before

welding so as to increase the areas of the surfaces in contact. Several such prepared surfaces are illustrated in Fig. 15-2. The joint is *scarfed* or prepared with a convex surface so that, when the bars are hammered together, any foreign material present on the welding surface will be forced out by

Continental Machines, Inc.

FIG. 15-1. Soldering a Stack of Metal Plates Using Acid-filled or Self-fluxing Solder Wire.

the hammer blows. After the weld is completed, the material is generally in an upset condition around the weld. This upset may be removed by subsequent heating and swaging. Fig. 15-3 illustrates the stages in the production of a small forged chain link. After the welding operation is

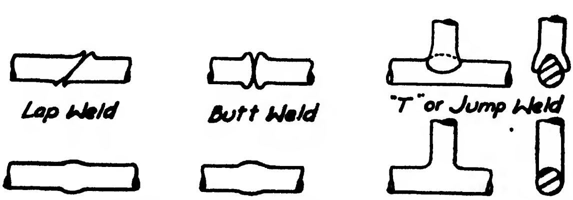


FIG. 15-2. Preparation and Completion of Forge-Welded Joints.

completed, the upset is swaged to the bar size by the use of top and bottom swages. The blacksmith forging or manual process is generally employed for special or repair work.

197. Resistance welding is another form of plastic welding and consists of passing a large current of electricity at a low voltage through

the work and across the joint to be welded. The heat developed at the point of contact, which is the point of highest electrical resistance, raises the work temperature to welding heat, and the metals are simultaneously pressed together by mechanical pressure which forces the softened surfaces together so that a weld is effected. Resistance welding machines embodying

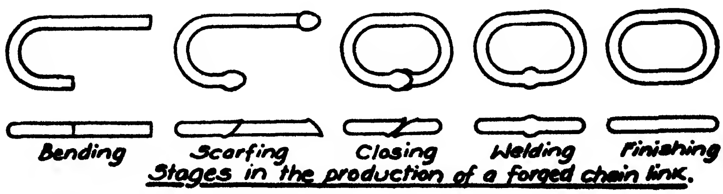


FIG. 15-3. Stages in the Production of a Forge-Welded Chain Link.

the current supply, the work-holding device, and the pressure media, are built in a large variety of types and sizes.

Spot welding is an important form of resistance welding and may be used to weld steel and other metal plates up to ½" thick. The principal elements of a spot-welding machine are illustrated in Fig. 15-4. The lower electrode E is stationary but the upper one may be lifted by a foot

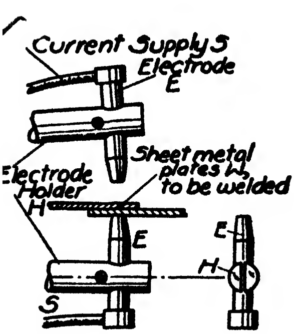


FIG. 15-4. Spot-welding; Work-setting Stage.

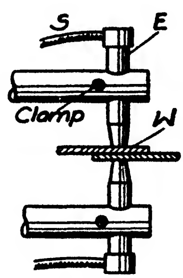


FIG. 15-5. Spot-Welding Process.

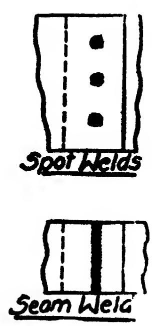


FIG. 15-6. Completed resistance Welds.

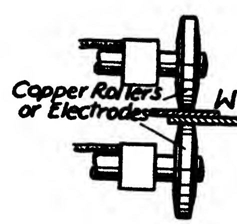


FIG. 15-7. Seam Welding Principles.

treadle on the machine. The electrodes are held in holders H, and can be adjusted in position to allow for plates of various thicknesses. Fig. 15-4 shows the beginning of the operational cycle and Fig. 15-5 illustrates the welding process. The upper electrode is applied to the plates with considerable pressure. Fig. 15-6 shows the result of three spot welds. The process is very rapid; a production of 2000 welds per hour in thin steel may be attained. The joint has considerable strength, since the sheets generally tear around the weld rather than separating at it.

Seam welding is analogous to spot welding with this difference: the electrodes are in the form of rollers, as indicated in Fig. 15-7, and the work moves in a direction perpendicular to the roller axes. The resulting seam weld is illustrated in Fig. 15-6.

Fig. 15-9 illustrates the principle of **butt resistance welding.** The parts to be welded are used as the conductors of the electricity and are pressed together at their ends or along their edges. The jaws for holding

"Welding Aluminum" (Aluminum Co. of America)

FIG. 15-8. Spot Welding an Aluminum Assembly.

the work are generally water-cooled, and are mechanically actuated so that they may be pressed together. The resulting weld is also indicated in Fig. 15-9. An upset or bulge is generally left at the weld.

Flash welding is similar to butt welding. The edges or ends of the work are adjusted to each other to draw a spark or flash until a welding temperature is reached, after which the current is turned off and the weld completed by pressure. This method may be used for heavy or for light sections and gives joints of high strength.

Fig. 15-10 illustrates an application of resistance welding. The part shown is made of steel. It is turned from solid bar stock whose outer

diameter is somewhat greater than that of the cup-shaped upper section. The turning process produces a large quantity of steel scrap and an excessive amount of time is spent in machining. Fig. 15-10 also shows the part made in two sections with just

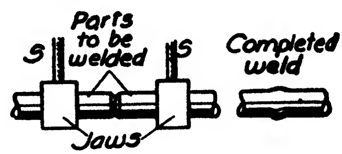
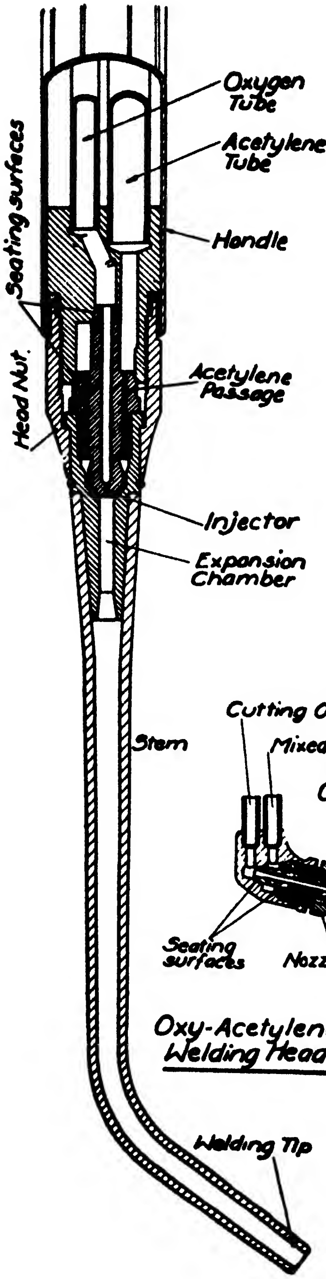


FIG. 15-9. Butt Resistance Welding Process.

enough material left for finishing. The cup or upper section is held in place by an electrode in a spot-welding machine, and the stem or lower section is held in position by a suitable clamp and serves as its own electrode. The completed part, after welding, is also shown. It is of course necessary to grind off the weld fin and finish the part, but the metal saved and the rough-machining time eliminated compensate for the additional operations.

198. Plastic weld-



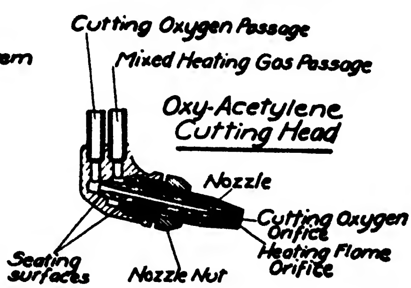


FIG. 15-11. Oxy-acetylene Torch.

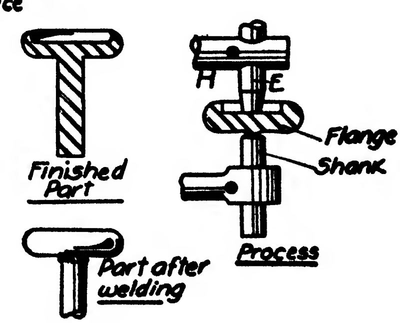


FIG. 15-10. Butt Resistance Welding Application.

ing, which is more often referred to as forge welding, requires the application of pressure as well as heat; in **fusion welding**, the metals are joined together without the application of pressure by heating the parts to be welded and fusing them together, or by heating both parts to be welded and joining them by the use of a filler metal. There are two important fusion welding processes: the first employs a mixture of oxygen and acetylene, or oxygen and hydrogen, and is termed **gas welding**; the second makes use of the electric arc as a heating medium and is termed **arc welding**.

Fig. 15-11 shows the **welding head** of an oxygen-acetylene torch for low-pressure gas welding. The oxygen and acetylene are admitted in separate tubes and the oxygen passes through the injector nozzle producing a slight suction. The acetylene, which flows through the acetylene passages, is thus drawn into the oxygen stream. Small changes in the oxygen supply

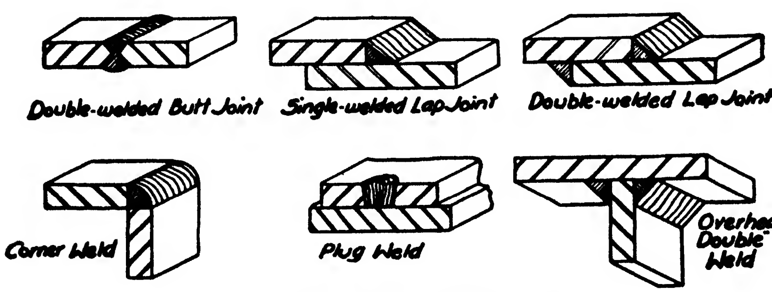


FIG. 15-12. Fusion-welded Joints.

will produce corresponding changes in the supply of acetylene, so that the proportions of the gas mixture, about 1:1 for neutral flame welding, remain substantially constant. The two gases are mixed and expanded in the expansion chamber. The utility of the torch comes from the high temperature of the flame, estimated at 5500° F. It is thus able to bring that part of the metal acted upon to the melting temperature before the heat can be lost by radiation or conduction. No filler material is used for thin sheets, but for sections of moderate and large size it is necessary to add weld metal from a welding rod or bar, which is usually of about the same material as the metals to be welded. The equipment necessary for gas welding comprises storage tanks for the gases, pressure regulators, and the torch.

In **gas welding**, the operator holds the torch in one hand, keeping the tip of the incandescent cone just off the base metals and oscillating the torch transversely, so as to maintain a melted zone on both sides of the vee, thus allowing proper penetration of weld metal additions. With his other

hand the welder holds the welding rod which is advanced into the flame for preheating, and then dipped below the surface of the molten puddle in the vee. As the puddle fills and slightly overflows the vee, both flame and rod are moved forward to begin a new puddle, and the deposit solidifies as an integral part of the base metal.

Various forms of **welded joints** are shown in Fig. 15-12. A butt joint may be welded from one or both sides. Material is often cut with U-shaped adjoining surfaces, and is then termed a U-butt joint, in contrast to the double-vee joint shown. The lap joints shown are fillet welds. In a plug weld, the welding metal is deposited through a hole punched in the upper plate. If the hole is punched through both plates, the weld is termed

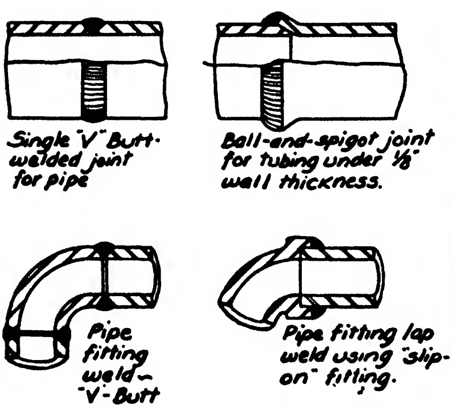
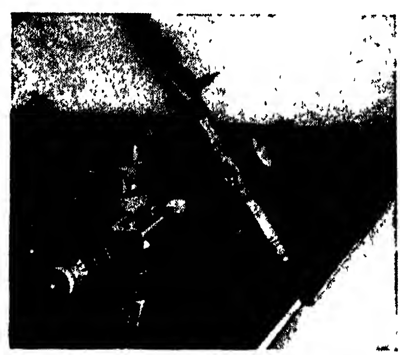


Fig. 15-13. Pipe Welding.



Air Reduction Sales Co.

Fig. 15-14. Portable Gas Cutting Machine.

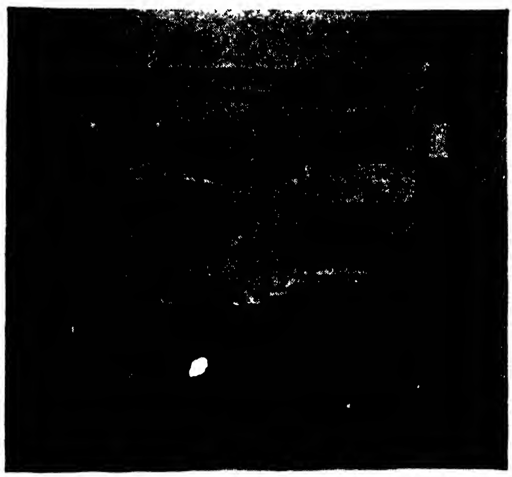
a rivet weld. In a corner weld, the outside corner is generally filled in. It is also possible to place a fillet weld in the inside corner.

Slip-on fittings shown in Fig. 15-13 greatly facilitate positioning and make welding easier, but they are more expensive than plain butt-welding fittings.

199. Gas welding apparatus may also be used for **cutting metals.** The **cutting head** illustrated in Fig. 15-11 is used for this purpose. The heating flame is fed by a mixture of oxygen and acetylene and heats the metal above its ignition temperature. The cutting oxygen flows through the central passage in the tip and unites with the heated metal which is literally burned away.

Fig. 15-14 shows a portable, variable-speed motor-driven machine for automatically cutting square or bevelled straight-line or circular edges. For straight-line cutting, the machine runs on steel tracks; by using two lengths of dovetailing tracks progressively, a straight line of any length can be cut

in one continuous operation. Fig. 15-15 shows a **stationary gas cutting machine** which is designed for the quantity production of an unlimited variety of shapes. The cutting torch is rigidly linked to a motor-driven electro-magnetized cam roller which travels along the face of a cam against which it is held by magnetic force. Another form of this machine has an attachment with a motor-driven manually-guided tracing device with which a blue print or drawing may be used. The operator guides the tracing wheel along the outlines of the drawing of the part to be cut and the cutting torch follows this path. The machine therefore serves as a rapid and economical means of cutting parts of irregular shape of which only one or a few are required.



Air Reduction Sales Co.

FIG. 15-15. Stationary Gas Cutting Machine.

Fig. 15-16 illustrates a machine for preparing pipe for welding. The torch cuts and bevels in one operation. The pipe is turned by hand or is held stationary, in which case the machine is caused to travel around the pipe by turning a crank. The machine may be equipped with two torches and used to cut out "frozen" screwed couplings and simultaneously bevel the pipe for rewelding.

Manufacturers of machine and press tools employ **flame cut steel members** as satisfactory substitutes for large castings. In one instance the usual cast frame for a large shear was replaced by various steel members, among which were two side plates approximately 5′ wide, 10′ long, and 8″ thick. These were shaped by a template-guided torch. In cutting interior through holes, the cut was started by drilling a small hole.

The cutting torch is extensively used for **cutting sprues** and **shrinkage heads** from cast iron and steel castings, for cutting up scrap, and for heavy salvage work of all kinds.

Steel and iron of practically any thickness can be cut by a device known as an **oxygen lance,** which consists essentially of a length of steel pipe connected through a hose to a regulated supply of oxygen. In operation the lance differs from the cutting blow pipe in that there is no heating flame to maintain the material at its ignition temperature, and in the fact that once

Air Reduction Sales Co.

FIG. 15-16. Portable Pipe Cutting and Beveling Machine.

cutting has started, the lance pipe itself burns and furnishes the heat necessary to keep the cut going. In order to start the lance, it is necessary to heat a spot on the metal to be cut, by using a blowpipe or by placing a redhot piece of iron on the spot where the cut begins. The oxygen lance may be used for piercing holes, which may be done very rapidly, two minutes being sufficient to sink a 2½″ diameter hole, 1′ deep, into a mass of hard iron or steel. Two lances may be used in combination for cutting; in one instance a hot top, 24″ thick and 66″ wide, was cut from a nickel steel ingot in 15 minutes.

In cutting, the lance is operated like a crosscut saw; the tip is moved slowly down the face of the cut. When the bottom is reached, the lance is lifted leisurely to the top and another depth of cut is started.

200. **Arc welding is a fusion welding process** in which the welding heat is provided by an **electric arc** set up between two electrodes or between the base metal and one electrode. Three types of arcs are in use: in the first, two carbon electrodes are employed; in the second, a carbon rod serves as one electrode and the base metal as the other; and in the third, which is the most important commercially, the metal to be deposited (the filler rod), serves as one electrode and the metal being welded as the other. The electric arc acts between the work and the filler metal as illustrated in Fig. 15-18. Direct current is generally used, about 400 amperes at 60 volts, and the arc temperature often attains 7000° F. The filler rod is held in a special electrode holder, which permits the operator to make contact with the work and then withdraw the rod sufficiently to establish an arc. The polarity of the electrodes is of importance since the greater heat is liberated at the positive electrode; for welding thin material, therefore, the work is made negative, and for welding heavy material the rod is made negative.

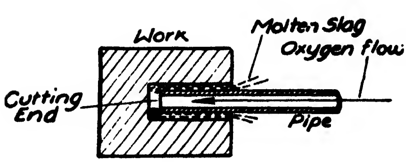
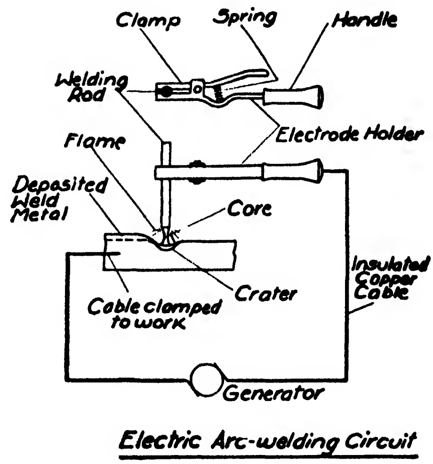


Fig. 15-17. Principle of the Oxygen Lance.



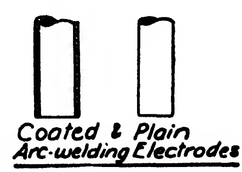


Fig. 15-18. Electric Arc Welding Principles.

Two forms of **filler rod** or electrode are used at the present time in the metallic-arc-welding process. For commercial steel welding, the **plain electrode** is generally a carbon-steel rod. In using the plain rod, the welding process tends to incorporate the dissociated nitrogen of the air in the weld and some oxidation takes place as the weld progresses.

The coated electrode is a carbon-steel filler rod that has been covered by some form of fluxing material. The coating includes a certain amount

Air Reduction Sales Co.

Fig. 15-19. One-arc Portable Motor-generator Unit for Electric Arc Welding.

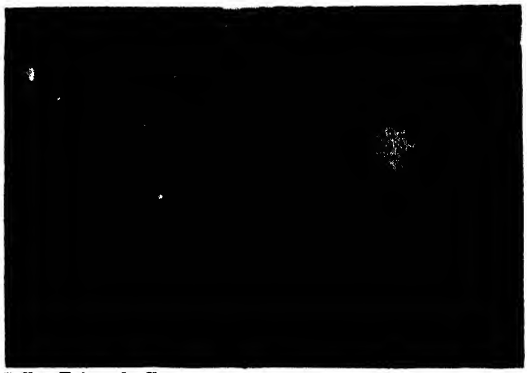
of cellulose, which burns to a gas, surrounds the arc, and assists in excluding the atmosphere, and thus produces the **shielded arc**. The coat-

Continental Machines, Inc.

Fig. 15-20. Arc-welding a Stack of Steel Plates Held in a Screw Press.

ing is prepared so that it will fuse at a slower rate than the core of the rod. Welds made with coated rods are less porous than those made with the

bare rod, and the material of the weld is more ductile. The coated electrode process should be continuous, however, and care should be taken to clean thoroughly each layer of weld metal as it is applied.



Cullen-Friestedt Co.

FIG. 15-21. Arc-welding the Flange on a Hoist Drum Held on a Hand-operated Welding Positioner.

201. Fig. 15-21 shows the process of welding a flange to a hoisting drum for a crane. The drum is mounted on a hand-operated **welding positioner** so that the joint to be welded will be easily accessible to the operator. The welding positioner has a table to which the work

Cullen-Friestedt Co.

FIG. 15-22. Arc-welding a Machine Frame Held on a Hand-operated Welding Positioner.

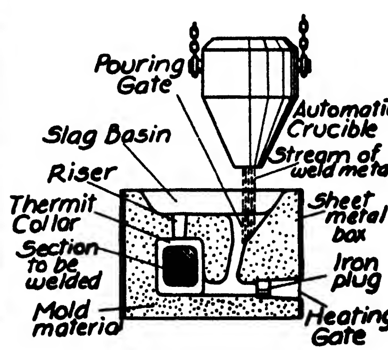


FIG. 15-23. Thermit Welding Principles.

is clamped. The table may be revolved by turning the upper hand wheel, and may be tilted from a horizontal position to an angle as illustrated, by turning the hand wheel at the left. The table may be adjusted vertically by

removing the pin and resetting it in one of the other four holes shown in the column. Fig. 15-22 shows welding operations on a machine frame, which is built up of steel plates, structural members, and cylindrical parts.

Welding positioners or fixtures are used to eliminate unnecessary crane or hoist handling, since the crane may be released for other work as soon as the part to be welded has been attached to the positioner. The use of this fixture also permits the operator to select the most advantageous position for welding different joints, and enables him to avoid overhead welding.

202. In **Thermit welding,** the weld material is deposited in one operation instead of in successive small increments, as in gas and arc welding. In the process, a wax pattern of the desired size and shape is constructed around the joint or region where the weld is to be made. A sheet-iron box is placed around the wax pattern and the space between the pattern and box is filled and rammed with sand. Pouring and heating gates, and risers, are cut in the sand and a flame is directed into the heating opening. The wax pattern melts and drains out but the heating is continued to raise the temperature of the parts to be welded. The **Thermit mixture,** which consists of finely-divided iron oxide and powdered aluminum, is placed in the crucible, ignited with magnesium or with a torch, and reacts to give alumina and molten iron. The temperature of the reaction will approximate 5400° F. The molten iron is poured from the crucible into the mold and fuses with the parts to be welded, forming a Thermit collar at the joint. If this reinforcement can be left in place, the weld is stronger than the original material.

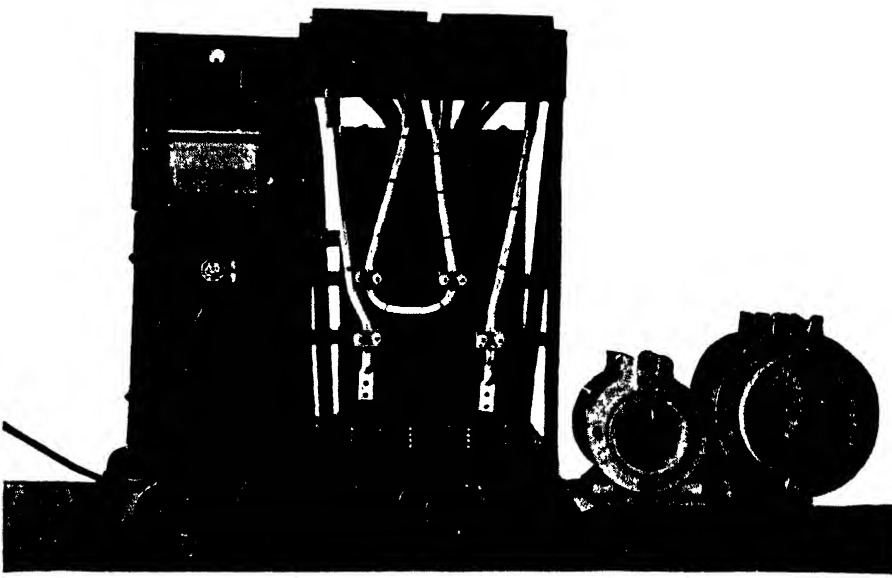
The Thermit welding process is usually employed for large iron and steel parts. It has been used in welding rail joints for which special molds have been developed. It has been successfully used for repair work in the welding of rudder posts and ship frames. However, gas and arc welding processes are preferred for parts with sections less than four square inches in area.

The Thermit welding process may be employed for welding non-ferrous parts by choosing a mixture of oxides which on reduction with aluminum will give an alloy approximating the material to be welded.

203. Hard-facing is the process of welding or fusing hardened material such as Stellite or tungsten-carbide alloys to tool edges or to the surfaces of other parts to give increased wear resistance. The process can be applied equally well to new parts before they are put in use, or to old, worn parts. Hard-facing is generally accomplished by welding the facing material directly to the base metal or by using an intermediate filler material. Some of the hard-facing alloys—tantalum carbide, for example—are brazed in place by using silver solder and a gas torch. Stellite may be applied by either the oxy-acetylene or the electric arc process.

In many cases, such as hard-faced aeroplane tail skids, the part may be put into service without any finishing; in other instances, as represented by hard-faced valve seats, hard-faced gages, etc., subsequent grinding and lapping operations may be required.

Hard-facing permits the use of cheaper base metals; it permits salvaging or reclamation of worn parts; and, most important of all, it will reduce costs by increasing the length of life of parts subjected to wear and abrasion.



Kuhlman Electric Co. (Detroit Electric Furnace Div.)

FIG. 15-24. Stress Relieving Equipment for Welded Joints in High-pressure Piping.

204. Stress relieving is a process of removing residual or "locked-up" stresses in members. Stress relieving in welded structures may be accomplished by heating the work to 1000° F. or higher, and then allowing it to cool for a period of from 10 to 48 hours. When available, a furnace should be used for heating. Small parts such as welded tool tips may be annealed by placing the part immediately after welding into a box of powdered asbestos and allowing it to cool for 24 hours.

Fig. 15-24 shows equipment for relieving stresses in welded joints of high pressure piping. At the right are shown portable induction rings for different sizes of pipe. The ring is hinged at the bottom and can be opened so that it may be clamped over the joint and used to concentrate heat in the weld metal and adjacent pipe wall. The ring is supplied with 60 cycle

current through a transformer which, with switches, controls, and a pyrometer, is mounted on the push truck shown at the left.

Induction rings are furnished for pipe sizes up to 24″ O. D. The electrical energy required varies with the pipe size. For instance, an 8″ pipe requires about 13 kilowatt-hours and the process takes from 3 to 4 hours if annealed at 1200° F.

Stress relieving may also be accomplished by peening with a hand or pneumatic hammer. In some instances each layer of weld material is peened before the next layer is applied.

Stress relieving is mandatory for certain classes of welded pressure vessels. In machine structures such as bases and brackets stress relieving is generally considered necessary to eliminate the danger of distortion or warping after the structure has been in service for some time.

205. Visual inspection of the outer surface of a fusion weld will give some indication of its soundness. Part or all of the welds in certain pressure vessels must be radiographed with an X-ray machine sufficiently powerful to reveal defects such as excessive porosity or points of defective fusion.

In pressure vessel and structural work, test plates are welded by the operator at the same time that the joints are welded. From the test plates, specimens for tensile, flexural, and density-determination tests are made.

206. For permanently joining metal parts, several methods have been developed, or have been adapted to new uses, in the last few years. One patented process is used for **joining pipe and fittings,** and utilizes the phenomenon of capillary attraction in making a soldered connection. Fig. 15-25 shows two copper pipes connected by a tubular coupling. This coupling has a cylindrical bore with an inside shoulder against which the tube ends fit. In each half of the coupling there is an annular groove or solder feed channel, with a solder feed hole entering the groove. In making the connection, the outer surface of the tube and the inner surfaces of the coupling are thoroughly cleaned, coated with soldering flux, and assembled. One-half of the coupling is heated with a blow torch or a gas torch and solder wire is fed through the solder feed hole. The solder melts as it comes in contact with the coupling, and is fed into the hole until it appears at the end of the coupling. The operation is then repeated for the other half of the coupling. It makes no difference where the feed hole is located; the solder will feed into a fitting where the hole is located on the underside as readily as if the hole is on top. The liquefied solder is carried around the entire surface between the pipe and fitting by capillary attraction.

Elbows, tees, crosses and other types of **solder fittings** are obtainable commercially in a wide variety of sizes. Valves and other accessories with patented solder fitting ends may also be obtained.

207. Electric-furnace welding or brazing is a comparatively new method of joining steel parts and non-ferrous parts. An electric furnace utilizing a belt conveyor made of a heat-resisting alloy is illustrated in Fig. 15-26. The equipment consists of a heating chamber filled with a reducing gas, in which the work is heated to the proper brazing temperature; and a gas-filled cooling chamber through which the work passes after leaving the furnace proper. Gradual cooling insures a complete absence of internal stresses and provides surfaces that are free from scale and oxides.

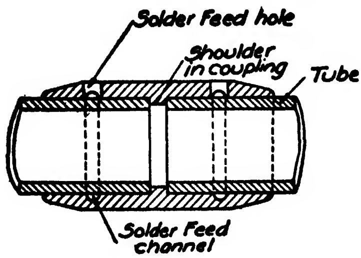
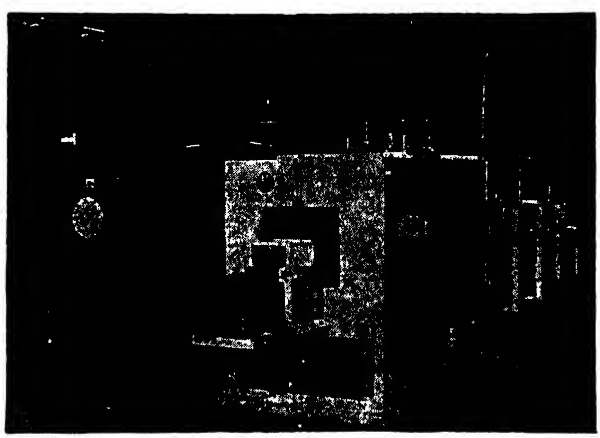


Fig. 15-25. Solder Fitting.

Fig. 15-27 illustrates a section of a brass tube with a flanged end. In the fitting at the left, the tube and flange are threaded, assembled and manually soldered with a tin-lead solder. The replacement fitting at the right is designed for **electric-furnace brazing.** The hole in the flange



Electric Furnace Co.

Fig. 15-26. Continuous Brazing Furnace with Endless Belt Conveyor of Heat-resisting Alloy.

is a light press fit on the tube, and is counterbored at its upper end to receive a single strand or ring of copper alloy brazing wire about $\frac{1}{16}''$ in diameter. The assembled unit is placed on the moving conveyor belt. The flange and tube attain the furnace temperature, and the wire ring becomes liquid and is drawn through the joint by capillary attraction, wetting the entire surface and forming a fillet at each end of the joint. The work then moves out of the furnace and into the cooling hood where the joint solidifies.

Extremely tight fits in the joint will enhance, rather than prohibit, the perfect flow of brazing material into the joint. Effective brazing cannot be expected if the surfaces of the joint are not clean, although the reducing action of the gas atmosphere used in the furnace will normally clean the parts of light oxides or oil and soot films.

The brazed replacement of Fig. 15-27 is less expensive than the original design for several reasons: by eliminating threads, a tube of thinner wall section, as illustrated, was possible, and the costly threading operations were dispensed with; a separate annealing operation was eliminated since the operation of heating for brazing purposes served as an annealing treatment.

A recently developed light-weight airplane engine has a crankcase and a cylinder block made of chrome-alloy high tensile strength steel. Cylinders and cooling jackets are cut from tubing; other parts from sheet material. Parts for the crankcase are assembled, their joint edges coated with copper alloy paste, and brazed in an electric furnace. Most of the machining operations usually required for cast crankcases may be dispensed with and the entire engine weighs about eight-tenths of a pound per horsepower.

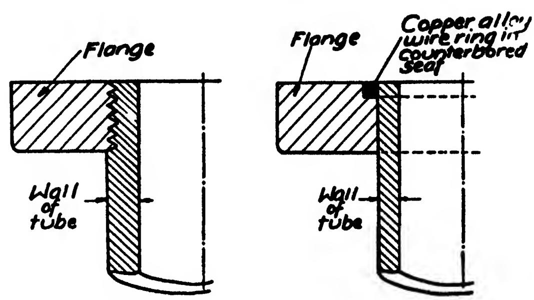


FIG. 15-27. Tubing with Attached Flanges.

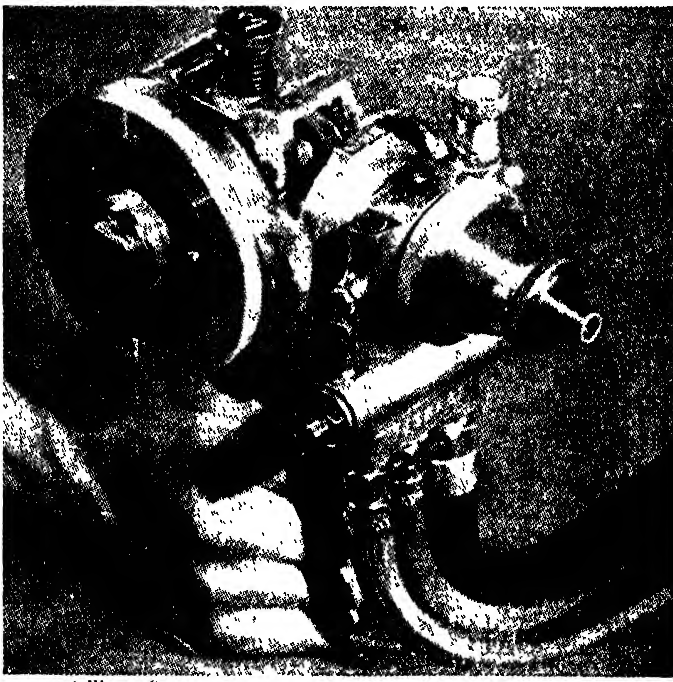
208. **Metallizing** is a process of spraying molten metal on a surface which is to be coated or built-up. Fig. 15-28 shows a **metal-spraying gun** which has two essential elements: an air-operated turbine for feeding the wire which provides the deposited metal; and a gas head for melting the wire. The wire enters the gun at the rear, and is fed forward by a pair of rollers which are driven by reduction gears from the turbine. The gas head contains a valve which supplies oxygen and gas for the cone of flame which melts the wire as it passes through. The metal in liquefied form is picked up by the air blast surrounding the cone of flame, atomized, and impelled from the gun.

Metal spraying guns generally use wire in sizes from number 10 to 18 B. & S. gage, although rods up to $\frac{3}{16}''$ in diameter are used in some instances where heavy metal deposits are required. Hydrogen, coal gas, and acetylene may be used as fuel, and can be obtained in tanks which are connected by hoses to the gun.

Another type of gun largely used in England receives the metal in finely powdered form. The powder is pneumatically conveyed to the gun and

melted and atomized by the flame and air blast. In certain applications of the powder spraying process, non-metallic material has been employed.

A wide range of both ferrous and non-ferrous metal wire can be employed for metal-spraying. The bond between the deposited coating and the base metal of the original part is purely mechanical, and is brought about by having the molten metal particles travel through the air and become semi-molten. The particles then strike the surface of the base metal with



The Metallizing Co. of America, Inc.

FIG. 15-28. Metallizing Gun for Hand Operation.

a sufficiently high temperature and velocity to adhere to the surface. To illustrate, if the gun is held too far from the part to be surfaced, the particles will not adhere; if the gun is held too close to the surface, the sprayed metal will run off.

The surface to be metal-sprayed should be rough so that proper adhesion of the coating will be effected. In shaft rebuilding, for example, the surfaces to be sprayed should be left rough-turned. For other applications sand-blasting is required. The gun may be held by hand as illustrated, but tool post mounting devices for lathes and other machine tools may be obtained.

Metal spraying is used for many purposes. Worn bearings on shafts and spindles can be readily restored to original dimensions with any desired metal or alloy. Low-carbon steel shafts may be supplied with high-carbon steel journal surfaces, which can then be ground to size after spraying. By using babbitt wire, bearings can be lined or babbitted while rotating. Pump shafts and impellers can be coated with any desired metal to overcome wear and corrosion. Valve seats may be re-surfaced. Defective castings can be repaired by filling in blow-holes and checks.

The application of metal spraying to the field of corrosion resistance is growing, although the major application in this field is in the use of sprayed zinc. Tin, lead, and aluminum have been used considerably. The process is used for structural and tank applications in the field as well as in the shop.

CHAPTER 16

MISCELLANEOUS UNIT-PRODUCTION SYSTEM PROCESSES

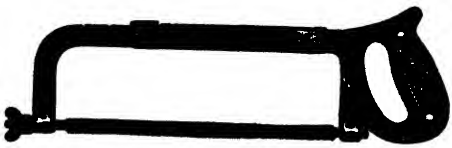
209. Hand sawing is often resorted to in unit-production system operations when other methods such as milling are impossible, or when it is possible to save time by eliminating clamping and set-up operations. Fig. 16-1 shows a **hand hacksaw** frame and blade; the frame is furnished with a so-called "pistol grip" for lessening fatigue of the user. The blade has saw teeth along one edge, and holes at each end to fit pins in the frame. Blades of either carbon, high-speed, or tungsten alloy steels are commercially available. Flexible back blades in which the teeth only are hardened are used for cutting in awkward or strained positions. The frame of Fig. 16-1, however, will permit using a blade in four positions and is adjustable for blades from 8″ to 12″ long. Fig. 16-2 shows a hacksaw with a plain handle for cutting small pipe, conduit, and the like, which can often be used in holes where the conventional frame will not enter.

Hacksaw blades are made with pitches from 6 to 32 teeth per inch. As a general rule, as coarse a pitch as possible is used, since this selection gives plenty of chip clearance. One manufacturer recommends eighteen teeth per inch for the usual run of hand work. In cutting tubing and sheet metal work, however, a coarse pitch blade may straddle the section and strip the blade teeth. Consequently a blade with 24 or 32 teeth per inch may be advisable.

210. There are three types of **metal-cutting saws** in commercial use: power hacksaws, circular saws, and band saws. Fig. 16-3 shows a **power hacksaw** which consists essentially of a frame carrying a hacksaw blade and a vise for holding work. The machine illustrated has an automatic feed with an arrangement to lift the blade clear of the chips on the return or non-cutting stroke. The vise is adjustable for angular cutting. The machine is motor-driven and has a pump to supply coolant for cutting.

Fig. 16-4 illustrates a **hydraulically-operated hacksaw** with an hydraulic bar feed, cutting sixteen pieces of stock at one setting. The bar is automatically fed forward for each cut, the length of which is determined by an automatic length gage. The vise opens and closes, and the saw blade is fed down on the work and lifted on the return stroke. No operator is required after the machine starts the cycle. The machine stops when,

except for small end pieces, the bar stock is cut up. The saw feed mechanism automatically adjusts itself to the shape or size of the work being cut so that rounds or thin sections are cut more rapidly than square sections of the same height, although the blade travels the same distance.



L. S. Starrett Co.

FIG. 16-1. Hand Hacksaw.

L. S. Starrett Co.

FIG. 16-2. Narrow Frame Hacksaw.

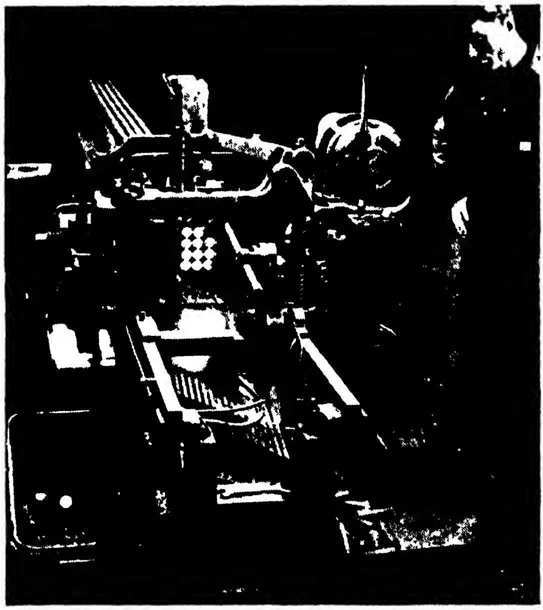
A **cold saw** is a metal-cutting machine which uses a disc saw similar to a milling cutter. Fig. 16-5 shows a cold saw with an inserted tooth cutter, sawing gear blank discs from a 9″ diameter SAE 1040 bar.

Peerless Machine Co.

FIG. 16-3. Power Hacksaw.

The machine has an hydraulic feed and a mechanically driven saw which *cuts up*. Cutting speeds of 35 to 70 feet per minute can be obtained.

Friction saws are used for cutting structural shapes and bars. The saw blades are circular, with vee-shaped peripheral teeth, are generally water-cooled, and are run at speeds up to 20,000 feet per minute. Large



Peerless Machine Co.

Fig. 16-4. Hydraulically-operated Metal Sawing Machine.

Consolidated Machine Tool Corp. of America

Fig. 16-5. Cold Saw Cutting Off Machine.

sections may be cut in but a few seconds. In some of the larger machines the work is rotated on an axis parallel to the blade axis, at a speed of about 3 feet per minute to prevent contact with any large area of metal, produce a cleaner cut, and increase the rated capacity of the saw.

Thin abrasive wheels are used for cutting extremely hard materials, such as hardened high-speed steel, drill rod, glass tubing, or materials which may be abrasive in character.

Continental Machines, Inc.

FIG. 16-6. Spiral Cut-out, Sawed in Four and One-half Hours.

Metal-cutting band saws are essentially similar to wood-cutting band saws. The saw blades are obtainable in widths from $\frac{1}{16}''$ to $\frac{1}{2}''$; as wide a blade as possible is employed; the blade width is generally limited by the minimum radius to be cut. Ordinarily the minimum radius that a blade of a given width will cut is about two and one-half times the saw width. Saws are generally made .025″ wide, and the teeth have two degrees of set: *light-set,* cutting .032″ wide; and *heavy-set,* cutting .042″ wide. Heavy-set saws allow greater freedom for the back edge of the saw and permit smaller radii to be cut.

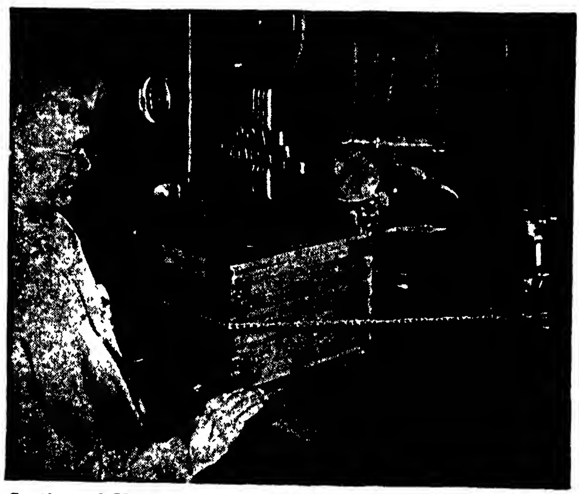
Continental Machines, Inc.

FIG. 16-7. Punch and Die Cut from One Piece of Steel.

Metal cutting band saws may be used for external or internal cutting. In **internal cutting,** a starting hole is drilled through the work and the saw band is cut or broken and inserted through the hole. The band is then clamped and welded in a special welding attachment on the frame of the machine. After welding, the joint is annealed and ground on its surface. The joint in the band is a butt-welded joint, can hardly be distinguished from any other part of the saw, and can be made in about one minute.

The band saw may be used to cut **mating punches and dies from the same block** as shown in Fig. 16-7. Since both the punch and die are tapered, the upper or cutting edge of the die is smaller than the lower or cutting edge of the punch; even though the two are cut from the same block. By a patented method, the starting hole is so positioned that it does not touch the cutting edge of either punch or die. After sawing, the punch and die are of course accurately fitted and finished.

The band saw also finds extensive application in the **manufacture of sheet metal blanks** where quantities are too large for individual production, but not sufficiently great to warrant the expense of a die set. The



Continental Machines, Inc.

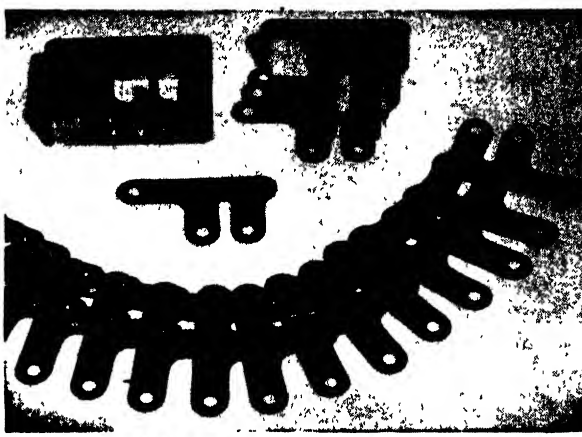
FIG. 16-8. Sawing Short-run Sheet Metal Parts.

metal sheets for a particular short-run job are first stacked and compressed tightly in a vise or press and soldered or welded at the corners. The outline of the required part is then drawn or scribed on the top sheet. The stack of sheets is then sawed out on the band saw as illustrated in Fig. 16-8. This illustration shows 65 sheets tack-welded at the corners to make a stack whose height is within ½″ of the saw capacity. Fig. 16-9 shows fifty electric switch part blanks, of .035″ thick cold rolled steel, ***stack-sawed*** at one time.

211. Files are used for smoothing surfaces, breaking corners, and sharpening tools. The term **cut** comprises both the degree of coarseness and the character of the teeth. There are three types of cut: ***single-cut, double-cut,*** and ***rasp***. These classifications are further subdivided into the following, which indicate the decreasing size of the teeth: coarse.

bastard, second-cut, smooth, and dead smooth. A **single-cut** file has single rows of parallel teeth extending the length of the file at an angle across its face. A **double-cut** file has two parallel rows of teeth crossing each other. The first row is usually coarser and deeper than the second row. The teeth of a double-cut file are sharp points, instead of straight edges as in the single-cut file. For this reason they cut more rapidly but not as smoothly as the single-cut. The teeth of a **rasp** are individual, or disconnected.

The *length* of a file is the distance between the point, which is the end opposite the *tang*, and the *heel*. A *blunt* file is one that has the same width and thickness from heel to point. A *taper* file decreases in width or thick-



Continental Machines, Inc.

FIG. 16-9. Electric Switch Part Blanks Produced Simultaneously by Contour Sawing.

ness, or both, from heel to point. A *safe edge* on a file is one that is smooth and has no teeth. The safe edge permits the file to be employed in a corner for filing one surface without danger of marring the adjacent surface.

Fig. 16-11 illustrates a few representative file sections. Mill, flat, hand, and pillar files are of rectangular section. The *mill* file is single-cut, tapered in both width and thickness, and is used for machine filing and draw-filing. The *flat* file is double-cut and tapered and is used for miscellaneous operations. The *hand* file is double-cut, of parallel width and tapered thickness, and has a safe edge. It is used principally for finishing flat surfaces. The *pillar* file is similar to the hand file, but is narrower and may have two safe edges.

Half-round files are tapered and made with double-cut curved surfaces and single or double-cut flat surfaces. They are used for hollow surfaces,

holes and like applications. *Round* files are both single- and double-cut, are tapered, and are used for fillets and holes. *Hand saw* files are single-cut, tapered to a point, and are used for saw filing. *Three-square* files are similar in shape to the hand-saw file, but have sharp corners, are generally double-

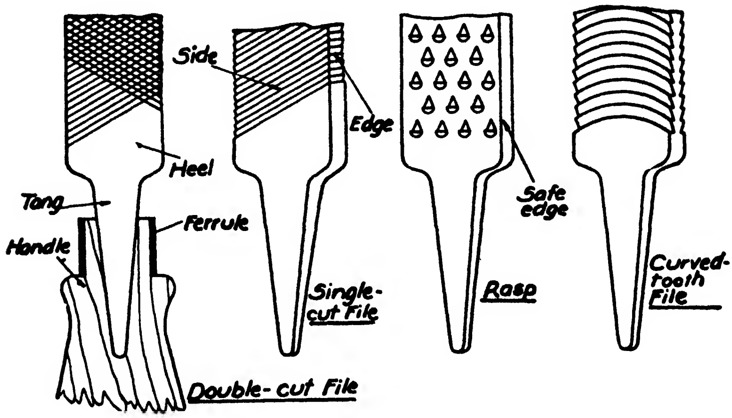


Fig. 16-10. File Types and Nomenclature.

cut, and tapered to a blunt end. Their principal application is for sharp corner filing. *Knife* files are generally double-cut and are used for corners and the like.

Surface or cross filing is an operation that requires skill; in modern practice it is used for finishing purposes only, since it is much more eco-

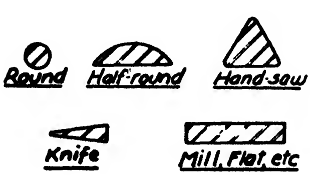


Fig. 16-11. Representative File Sections.

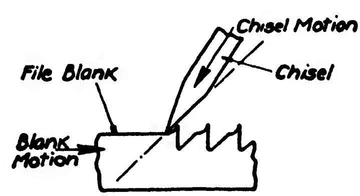


Fig. 16-12. File Manufacture.

nomical to remove any appreciable quantity of material by machine. **Draw filing** is performed by pushing the file sideways using short strokes; it is used primarily for truing surfaces and removes very little material.

The *rasp* is used principally in wood-working or for very soft metals where the filings tend to clog the teeth of the tool. Another file used for

soft metals such as aluminum is the *curved tooth file,* which removes metal rapidly and produces a smooth surface. A *file card* is used for cleaning files. It resembles a brush, having very short closely-set wire bristles which are scuffed along the file surface parallel to the tooth cuts.

Photo by E. S. Miller, Jr.

FIG. 16-13. Surface or Cross Filing.

Fig. 16-12 illustrates the principle of **file manufacture.** The teeth are cut by forcing the power-operated chisel into the softened steel blank, while the blank moves in the direction indicated by the arrow *F*. The

Photo by E. S. Miller, Jr.

FIG. 16-14. Draw Filing.

toothed blanks are hardened after cutting. Rasp teeth are made by employing a sharp-pointed punch for each tooth.

A **file jig,** Fig. 16-16, is used as a gage or template for filing parts to shape and size. It consists of a hardened steel plate with a bevelled

gaging edge. In the operation illustrated, the holes in the part are placed over the jig pins, the part and jig are clamped in a vise, and the projecting contour of the part filed to shape. File jigs are employed for shapes that are difficult to mill, and are also used where the quantity of pieces required does not warrant the expense of a special milling cutter.

Photo by E. S. Miller, Jr.

Fig. 16-15. Cleaning a File with a File Card.

212. There are several types of **filing machines** used in industry. One very common type operates on the principle of the jig or scroll saw, and employs a file which reciprocates vertically through a hole in a table which may be placed either in a horizontal or an angular position. The file cuts on the down stroke, and the operator moves the work as required either by hand, or in some instances, by a screw feed.

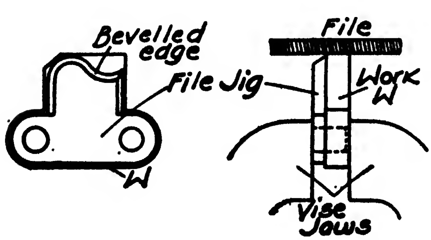
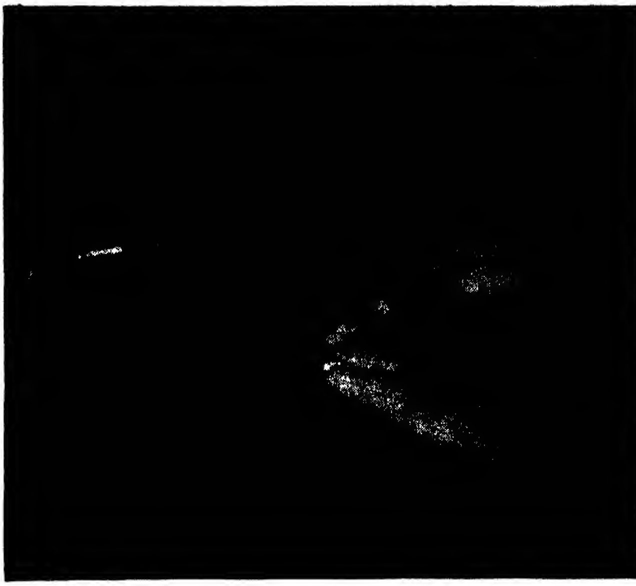


Fig. 16-16. Filing Jig.

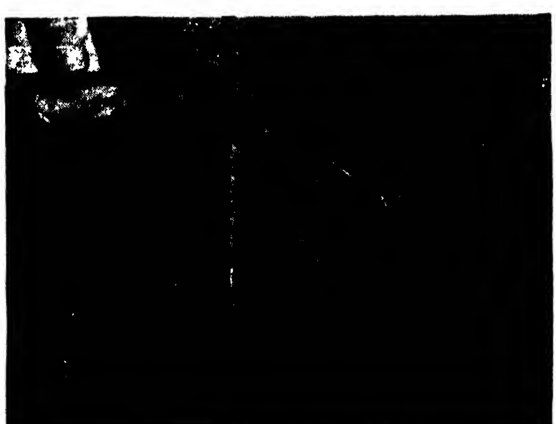
Fig. 16-17 shows **continuous filing** operation. A flexible steel band with attached file sections, as shown in Fig. 16-18, is used on a band saw in place of a saw blade. Internal as well as external filing can be easily accomplished by unhooking the band at the joint, slipping it through the hole in the work, and rejoining it.

Rotary files and burrs are used in finishing die cavities and like applications. The file is generally driven by inserting it in a drilling machine spindle, or by using a flexible-shaft drive or a pneumatic machine to permit hand manipulation for varying the position of the file. Files and burrs are



Continental Machines, Inc.

FIG. 16-17. Continuous Filing on a Band Saw.

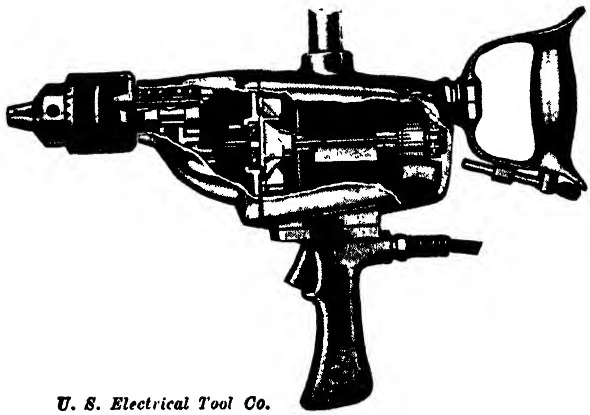


Continental Machines, Inc.

FIG. 16-18. File Band.

similar to the die-sinking burrs shown in Fig. 13-13, but have smaller shanks and may be of almost any shape.

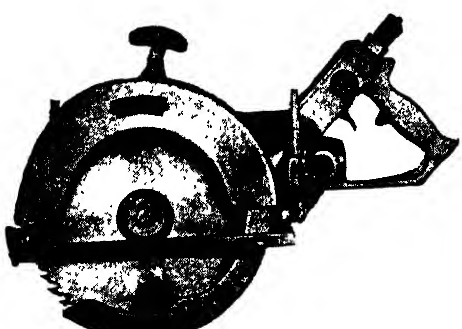
213. **Portable electric tools** are extensively employed in both wood-working and metal-working processes. Fig. 16-19 shows a **portable**



U. S. Electrical Tool Co.

FIG. 16-19. Electric Portable Drill.

electric drill with a self-contained motor and a trigger switch. The drill is fitted with a three-jaw chuck, has a spade-type handle on the end, and a detachable side handle opposite the pistol grip handle. Fig. 16-20 illustrates a **portable electric saw** which is used for cutting wood, plaster board, slate, marble, and soft metals. Cross-cut, ripping and other types of saws may be used for wood, while thin abrasive discs 1/8" thick are generally employed for other materials.

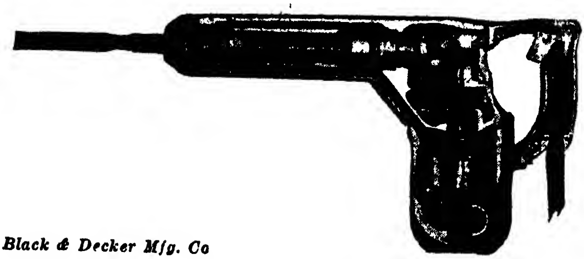


U. S. Electrical Tool Co.

FIG. 16-20. Portable Electric Saw.

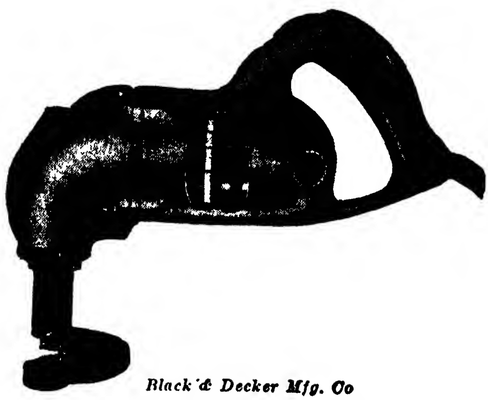
Portable electric hammers such as that shown in Fig. 16-21 are used for drilling and channeling in concrete, stone and brick, for calking seams in pressure vessels, and for removing scale or deposit in boilers, etc.

The **portable electric shear** illustrated in Fig. 16-22 has a shearing action accomplished by the rapid reciprocating action of a vertical blade against a stationary horizontal blade, set in a special shoe which indicates the correct cutting angle and adapts the tool to all types of cutting. The



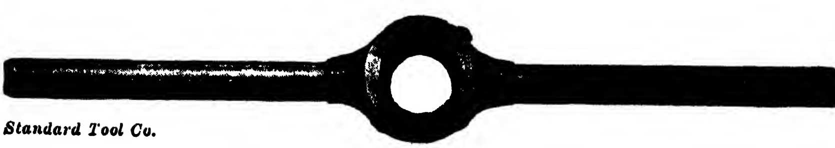
Black & Decker Mfg. Co

Fig. 16-21. Portable Electric Hammer.



Black & Decker Mfg. Co

Fig. 16-22. Electric Shear.



Standard Tool Co.

Fig. 16-23. Die Stock.

Standard Tool Co.

Fig. 16-24. Round Adjustable Dies for Threading Screws.

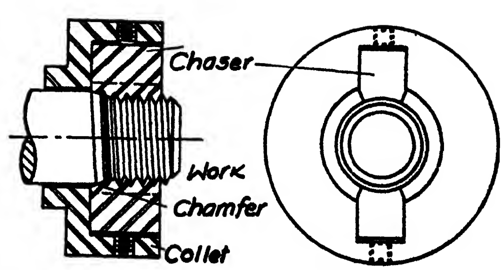


Fig. 16-25. Two-piece Adjustable Die.

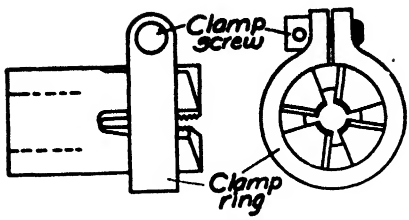


FIG. 16-26. Spring-type Die.

shear can cut to a radius as small as ¾″ and has a cutting speed varying from 1,500 to 2,500 strokes per minute. The shear shown can cut a maximum thickness of No. 16 U. S. Standard gage steel plate.

214. Many **external screw threads**, particularly in the smaller sizes, are cut with **dies** because of the

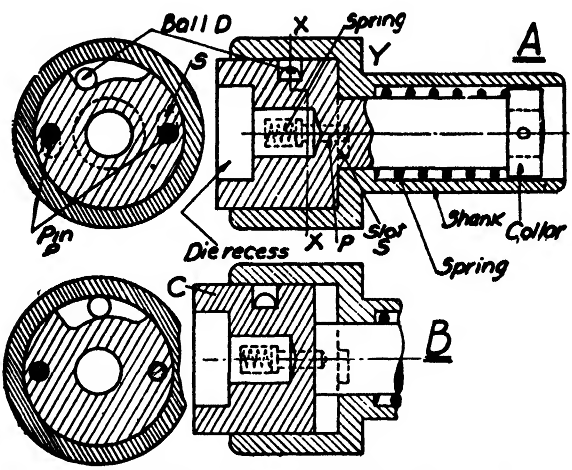


FIG. 16-27. Releasing Die Holder.

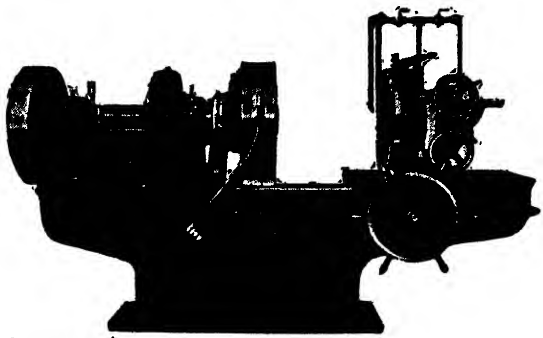
rapidity with which the operation may be accomplished. American Standard, Sharp "V", Whitworth, and Acme threads may be die-cut; square threads are rarely die-cut on account of the difficulty of procuring a clean accurate thread. Die-cut threads may be cut by hand-operated tools or in turret lathes and automatic screw machines.

Fig. 16-23 illustrates a **die stock** for the **round adjustable dies** of Fig. 16-24. Dies of this character are slotted so that some size adjustment may be obtained by the die stock set screws. Round dies are stocked in both the fine and coarse thread series

Landis Machine Co.

FIG. 16-28. Self-opening Die Head with Tangential Chasers. for Turret Lathe Work.

in diameters from No. 0 to $\frac{7}{8}''$. Fig. 16-25 shows an adjustable or **chaser type of die** composed of a collet which carries two die blocks or **chasers**



Landis Machine Co.

FIG. 16-29. Pipe Threading and Cutting-off Machine.

which may be adjusted by means of set screws. The blocks are seated in vee-grooves in the collet to prevent any axial motion. The collet is held in a die stock similar to that of Fig. 16-23. The two piece or chaser type of die is preferable to solid or adjustable split dies for cutting comparatively large screw threads, because solid dies are more subject to slight distortion in hardening. The inserted chaser type of die may be more easily sharpened, and can be renewed without discarding the collet by inserting a new set of chasers when the first set is worn out.

Photo by E. S. Miller, Jr.

FIG. 16-30. Cutting Off Pipe.

Fig. 16-26 shows a **spring type threading die** which is used on turret lathes and automatic screw machines. The die is adjustable to some extent by the clamp ring shown. Fig. 16-27 shows a **releasing die holder** for turret lathe work, which carries a round solid die. This holder is used when a thread is to be cut close to a shoulder. The work rotates, and the stationary die is fed forward, cutting the thread as shown at *A*. When the forward motion of the die ceases, the rotation of the

thread on the work draws section C of the die holder forward until the pins P are clear of the slots S in the body Y (which is held in the turret of the machine) as shown at B; the die then revolves on the work as long as the work turns in the cutting direction. When the work spindle is re-

Photo by E. S. Miller, Jr.

Fig. 16-31. Reaming the End of a Pipe.

versed, the die starts to rotate with it in the same direction, but the reverse movement is checked by the ball D and the stationary die is then run off the finished threads as the spindle continues its reverse rotation. The releasing type of die holder is used to prevent stripping the thread or break-

Photo by E. S. Miller, Jr.

Fig. 16-32. Threading Pipe with a Ratchet Die Stock.

ing the die if the machine spindle is not reversed at the instant the forward motion of the die ceases.

The dies of Fig. 16-24 to 16-26 are removed from the work by turning the die or the work in a direction opposite to the cutting direction. Automatic or self-opening dies are provided with a mechanism which will

Photo by E. S. Miller, Jr.

FIG. 16-33. Attaching a Pipe Fitting, Using a Stillson Wrench.

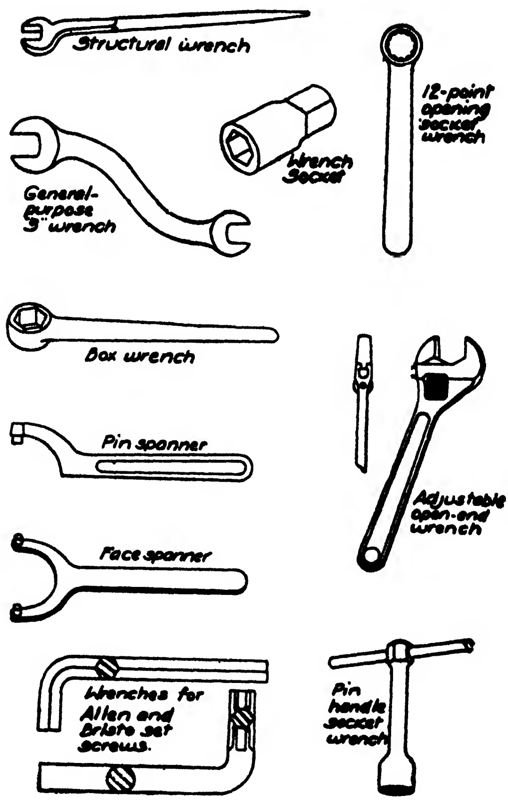


FIG. 16-34. Wrenches.

permit the chasers to be retracted radially so that the die may be removed with a single axial movement. Fig. 16-28 shows a **stationary threading die head** with a hand lever for self-opening action for use on turret lathes. The die itself has four tangential chasers which provide a cutting action similar to a lathe tool. The shank of the head is flexible and permits a floating action to compensate for misalignment between the die head and the work. The head can be obtained with an internal tripping arrangement to open the head automatically when the front end of the part being threaded makes contact with a stop bar in the bore of the head.

215. Fig. 16-29 illustrates a **machine for threading and cutting pipe.** The pipe is held in two universal chucks, one at the front and one at the rear of the rotating head at the left. The threading die is mounted on a slide at the right. A cross rail carries a cutting-off tool and a single point reamer to cut off the pipe end and finish ream or chamfer the interior edge. Machines of similar character are obtainable for bolt and stud threading.

216. Figs. 16-30 to 16-33 show the sequence of **operations in pipe fitting.** The pipe is held in a pipe vise that may be opened for inserting the pipe, which is then clamped between the fixed lower jaw and the adjustable upper jaw by the screw. The first operation, **cutting,** may be done by using a hack saw, but is more conveniently and quickly performed by using the pipe cutter illustrated. The cutter has two adjustable rollers opposed to a rotary cutting wheel. After cutting, the ratchet-operated **pipe reamer** shown in Fig. 16-31 is employed to remove the burr formed on the inner edge of the pipe so that flow in the pipe will not be obstructed. The pipe is then **threaded** with a ratchet die stock, Fig. 16-32, and a fitting is attached with a **Stillson wrench,** Fig. 16-33. This wrench has toothed jaws to grip the fitting properly, and is adjustable for various sizes of pipe and fittings. For large pipe, chain wrenches similar in principle to the band wrenches shown in Fig. 2-36 are often used.

217. Various types of **wrenches** are illustrated in Fig. 16-34. **Socket** or box wrenches are generally preferred to open end wrenches, since there is less danger of slipping over the corners of the nut. Open end wrenches can, however, be used in many places where socket wrenches will not enter. Pin and face **spanners** which have holes in the periphery or the face are used on round nuts. Pin handle wrenches, either of the socket or the square tip type, are used for chucks and fixtures.

CHAPTER 17

MASS-PRODUCTION SYSTEM MEASUREMENT

218. The mass-production system of manufacture differs from the unit-production system in several important details, the most important of which are: large-quantity production, transfer of skills, and interchangeability. Skilled artisans are generally required for precision manufacturing on standard machine tools. If, however, a suitable fixture for holding the work is designed and built, and if cutting tools are adjusted and set so that all that remains to be done by the operator is to insert the work in the fixture, start the machine, and then remove the work after the machining operation is completed, even an unskilled operator can produce accurate work. In other words, the skills employed by the designer of the fixture, the toolmaker or fixture builder, and the machine setter and supervisor, are transferred through the medium of the fixture and the set-up to the unskilled operator. The principle of **transfer of skills** is of course generally applicable only to repetitive operations, where the saving in labor cost will compensate for the cost of the original fixture and its maintenance.

The principle of **interchangeability** requires manufacture to such specification that component parts of a device may be selected at random and assembled to fit and operate satisfactorily. Interchangeable manufacture, therefore, requires that parts be made to definite limits of error, and to fit gages instead of mating parts. Interchangeability does not necessarily involve a high degree of precision; stove lids, for example, are interchangeable but are not particularly accurate, and carriage bolts and nuts are not precision products but are completely interchangeable. Interchangeability may be employed in unit-production as well as mass-production systems of manufacture.

In the mass-production system, the cost of parts is usually less, the production rate is much higher, and the quality of workmanship is more uniform than in the unit-production system. One extremely important advantage of interchangeable manufacturing lies in the availability of repair or replacement parts. A machine or device need not be sent back to the manufacturer if a part fails in service; another part of the same catalog number may be ordered and assembled with every assurance that it will fit and function as satisfactorily as the original part.

The principal disadvantage of the mass-production system lies in the heavy investment in tools, fixtures, and gages, on which depreciation and interest charges are continually accumulating. The principal item of expense in the unit-production system is that of labor cost, which may be curtailed in times of depression. In the mass-production system the fixed charges on the equipment continue regardless of the production rate, and are relatively higher for small than for large volumes. Another disadvantage of the mass-production system is that the investment in special equipment may tend to discourage minor changes and improvements in the design of the product.

219. Interchangeable manufacturing procedure requires definite specification, not only for the **size** of the part, but also for the **permissible error** in each dimension. It is practically impossible to manufacture to an exact dimension, and the permissible error in each dimension of a part is therefore given either by direct specification or by implication. Such specification not only relieves the production operator from the necessity of exercising his often imperfect judgment as to the degree of precision required, but is also economical in that it indicates where a comparatively low degree of accuracy will suffice for the successful functioning of the part.

Interchangeable manufacturing specification is usually based, therefore, upon the **limit system of dimensioning,** which is a recognition and control of the inevitable errors in manufacture.

In **limit dimensioning, nominal** size is a designation given to a dimension which has no specified limits of accuracy but is a close approximation to a standard size. **Basic** size is an exact theoretical size from which all variations are made. **Allowance** is an intentional difference in the size of mating parts. **Tolerance** is the permissible variation in the size of a part. **Limits** are the extreme permissible dimensions of a part.

220. Two types of tolerance, **unilateral** and **bilateral,** are used in limit dimensioning. **Unilateral tolerance** as related to a basic dimension is in one direction only. For example, in a running fit, for a nominal size of 1¼", the hole size may vary between limits of 1.2500"-1.2514". The tolerance of .0014" is in one direction, above the basic size of 1.2500". The shaft size may vary between limits of 1.2484"-1.2470". The tolerance of .0014" in this case is below the basic size of 1.2484". The basic size, as a general rule, represents the most important dimension, in this particular case the minimum clearance or positive allowance of .0016". (The loosest fit or maximum clearance within the given limits will be .0044".)

A **bilateral tolerance** is one in which the variation from the basic size is in both directions. For example, in dimensioning the center distance

between a pair of holes in which the pins of a link are to fit, the distance may be given as 3.001″-2.999″, indicative of a bilateral tolerance of .002″ divided .001″ above and below the basic size of 3.000″. The center distance of the link pins would be dimensioned similarly, and the maximum error would not, therefore, exceed .002″ in either direction. If these holes, however, were used as bearing holes for spur gear shafts, the tolerance on the center distance should be *unilateral* and positive, as 3.000″-3.002″, to eliminate the danger of the gear teeth meshing too tightly.

It may be observed from the preceding discussion that a single theoretical allowance for a fit cannot be maintained, since the allowance is itself dependent upon the tolerances permitted in the mating parts. In some in-

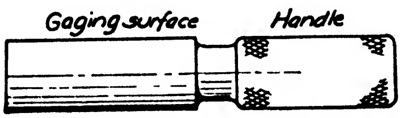


Fig. 17-1. Solid Single-diameter Plug Gage.

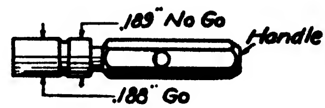


Fig. 17-2. Taper Insert Progressive Limit Plug Gage.

stances where a more precise allowance is desired, selective assembly is resorted to. **Selective assembly** consists of trial selection of mating parts so as to obtain a desired precision of fit. An example of this process is the assembling of ball bearings. All ⅜″ diameter balls are not alike. For instance, there may be balls of .3751″, .37505″ and .3750″ diameter. The balls are sorted into groups and assembled in races that are similarly selected. The assembled ball bearing is consequently not strictly interchangeable, since a replacement ball may be slightly under or over the size of the rest of the balls in the assembly.

Fractional dimensions on a drawing indicate that ordinary scale measurements are sufficiently precise, and thereby imply limits, in general, of plus or minus .010″ on each dimension.

221. Fixed gages are measuring tools that conform to established dimensions. They will show whether a certain size is correct or incorrect, but will not indicate the degree of error of the part. The term *fixed gage* does not mean that the gage cannot be adjusted. Many fixed gages have measuring points that can be adjusted for wear or for a limited size range.

Fig. 17-1 shows a **solid plug gage** for checking the size of a hole. If the gage enters the hole, it is an indication that the hole is large enough, but the operator must exercise judgment as to the amount of play or freedom that exists between the hole and the gage.

Fig. 17-2 shows a **progressive limit plug gage** that has two gaging diameters. This type of gage is also referred to as a **GO and NO GO gage.** If the GO portion of the gage enters the hole, it indicates

that the hole is large enough; if the NO GO portion does not enter the hole, it indicates that the hole is small enough. This type of gage can therefore be used by comparatively unskilled operators. As a matter of interest, even blind people are able to perform such gaging operations satisfactorily. The gage shown in Fig. 17-2 has a separable gaging member and handle. The handle may be made of common steel and may be used with a new gage plug when the original becomes worn. **Progressive gages** can only be used for through or open holes, but the hole may be checked in one operation. **Double-end plug limit** gages may be used for gaging either through or blind holes, but require two gaging operations for each hole that is inspected.

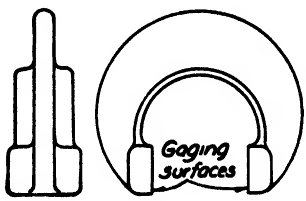


Fig. 17-3. Reference or Single-diameter Snap Gage.

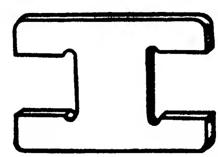


Fig. 17-4. Solid Snap Gage.

Gages up to 1½″ nominal size are made in the **taper-insert style;** larger sizes are made in the **end-locking style.** The NO GO gaging member is generally shorter than the GO member, not only because the NO GO member is subjected to less wear, but also to enable the operator to distinguish readily between the sizes.

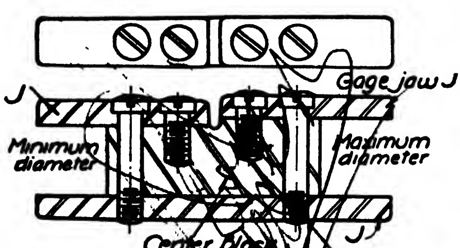


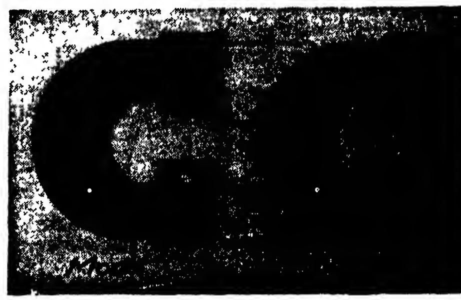
Fig. 17-5. Built-up Snap Gage.

222. Snap gages are fixed gages that are employed for external measurements. Fig. 17-3 shows a **single size snap gage** which is used for reference purposes only. Fig. 17-4 shows a **double-end solid limit snap gage** which may be made from sheet steel varying in thickness from ⅛″ to ½″. The gage may be made of high carbon steel or of case-hardened common steel. In each case the gaging surfaces are hardened, ground and lapped.

Fig. 17-5 shows a **built-up double-end snap gage.** The initial cost of this gage is greater than that of the solid gage, but the built-up gage may be restored after wear by simply removing the gage jaws *J*, and lapping

their surfaces plane. The gage size actually depends upon the center block which is at no time subjected to any wear.

Fig. 17-6 shows two types of **progressive adjustable limit snap gages** which conform to American Gage Design Standards. Model *C*, at the left, has a fixed single block anvil and two adjustable gaging buttons. Model *B*, at the right, has four adjustable gaging buttons. The AGD Model *A* snap gage has four cylindrical gaging pins instead of the flanged buttons of models *B* and *C* and is more convenient to use, although it is not as well adapted to gaging diameters close to a shoulder as the button type. These gages are provided with adjusting screws and with means for locking the gaging members in position after they are set to size. The gages can be sealed after setting so that no unauthorized adjustment of the instrument is possible. Adjustable limit snap gages generally have a range of adjustment of from ½″ to 1″, so that adjustment can be made for a variety of work as well as for wear in service.



Sheffield Gage Corporation

FIG. 17-6. Adjustable Limit Snap Gages.

Fig. 17-7 shows a master or **reference gage** which is used for checking the size of snap gages in use in the shop. The ends of the master gage

FIG. 17-7. Master Gage for Inspecting Working Gages.

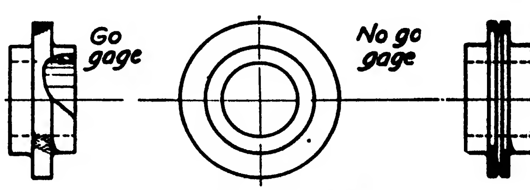


FIG. 17-8. Ring Gages.

are larger than the gaging members, so that injury to the gaging surfaces will be prevented if the gage is carelessly laid on a bench. The enlarged ends also prevent the use of the instrument as a plug gage.

223. Plain ring gages are external gages of circular form employed for the size control of external diameters. Up to about 1½″ nominal diameter, the gages are cylindrical with a knurled outer periphery. Ring gages above 1½″ are flanged, as illustrated in Fig. 17-8, to reduce weight

and facilitate handling. The NO GO gage is provided with an annular groove in its outer periphery as a means of identification.

224. Plug gages that are worn may be restored to size by plating with chromium and refinishing. Because chromium plating is brittle and likely to chip off in service, the entering end of a conventional plated gage may chip or peel after some use. Fig. 17-9 shows a chromium plated gage in which the end is stepped so that the usual feather edge of the plating is eliminated. Gages with **tungsten-carbide liners** or inserts are economical for extremely heavy duty and long life. Fig. 17-9 also shows a gage fitted with a groove to facilitate the entry of the plug into the hole. This feature is of particular value in gaging holes that are held to very close limits. It is also adapted for gaging operations on a machine where the work may not be moved, since it is not necessary to align the gage very carefully with the work. The groove may be interrupted for blind hole gaging as illustrated, or it may be continuous for through holes.

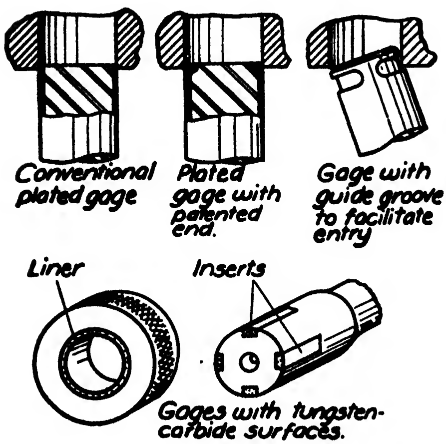


Fig. 17-9. Heavy-duty and Plated Gages.

As a general rule, **gage tolerance,** or the allowable error on gages themselves, is held to approximately 10% of the tolerance allowed for the piece to be gaged, or 10% of the difference in the diameter of a GO and NO

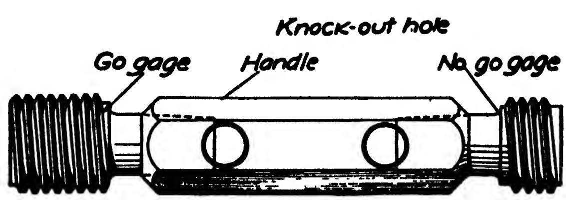


Fig. 17-10. Double-end Taper Insert Thread Plug Limit Gage.

GO gage for that part. The purchaser should in all important instances specify the gage tolerance.

225. Internal threads or tapped holes are generally tested with **thread plug gages.** The gages shown in Figs. 17-10 and 17-11 have sharp roots and relieved crests, so that the pitch diameter of the thread

is the element that is inspected. Very accurate threaded holes may be tested in three stages: the *root diameter* is checked by a plug gage; the *full diameter* of the thread is checked by a gage with relieved threads so that only the crests come in contact with the hole; and the *pitch diameter* is checked by a gage similar to Fig. 17-10 or 17-11.

External threads may be checked with **limit ring gages,** such as illustrated in Fig. 17-12, or with **thread snap gages,** Fig. 17-13. The snap gage has V-shaped instead of the usual flat-end anvils. As illustrated, it is comparatively easy to determine the error in the thread by using a thread snap gage, but the ring gage has a longer life.

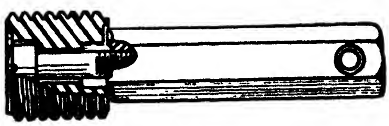


FIG. 17-11. End-locking Thread Plug Limit Gage.

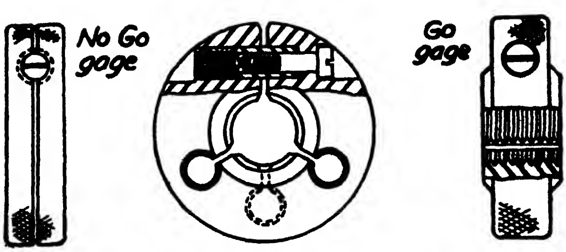


FIG. 17-12. Thread Ring Limit Gages.

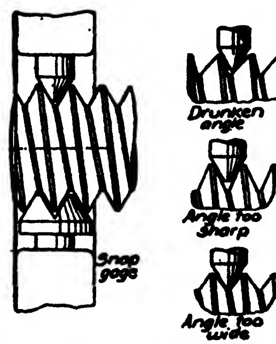


FIG. 17-13. Thread Limit Snap Gage.

226. Fig. 17-14 shows a **combination gage** for checking the thickness of the head, the body diameter, the body length, the thread and the overall length of a shoulder screw. The gage is made of case hardened sheet steel with inserted bushings for the thread gaging.

Fig. 17-15 shows a **set of gages** for checking the important dimensions on a slotted rod. A **snap gage** similar to that of Fig. 17-5 is required for the rod diameter. The **slot alignment gage** indicates such relation within .0005". In using the **straightness gage,** the work is placed in the groove and rotated by hand. If it rotates freely, the work is straight within a maximum limit of .001".

Fig. 17-16 shows a small crank for which all the dimensions that are important from the standpoint of interchangeability are given. A **progressive snap gage** for the crankpin, a **progressive plug gage** for the hole, and an **assembly gage** are required. The assembly gage is used to check the distance between the crank pin and shaft hole axes, and to

indicate whether the crankpin is parallel to the shaft hole. The distance from the axis of the stud S to the inner gaging edge is 1.030", which allows

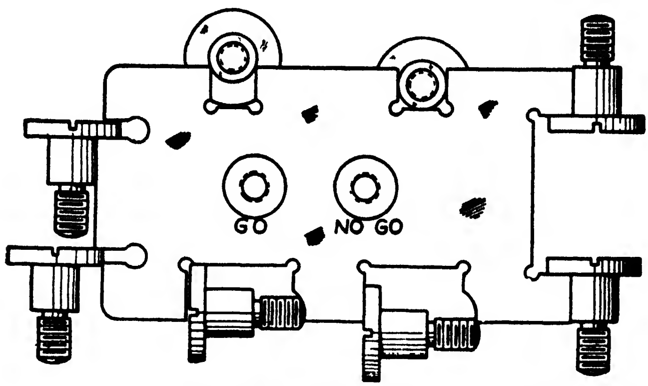


FIG. 17-14. Combination Gage for a Shoulder Screw.

the crankpin to pass if the center distance is at the low limit, the crankpin is at the high limit, and the shaft hole is at the high limit. The distance from the stud axis to the outer gaging edge is 1.472" so the crankpin may

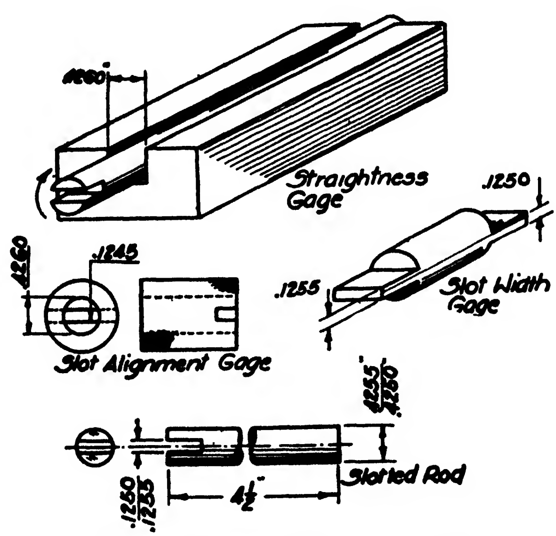


FIG. 17-15. Gages for a Slotted Rod.

pass if the center distance, crankpin diameter, and shaft hole diameter are all at the high limit. In operation, the crank is placed on the stud and rotated by hand to pass between the gaging edges.

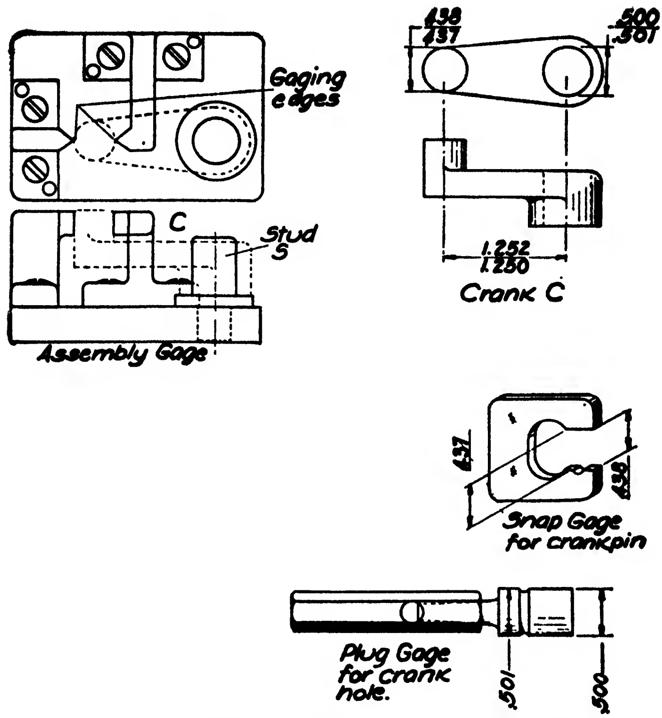


FIG. 17-16. Gaging Equipment for a Small Crank.

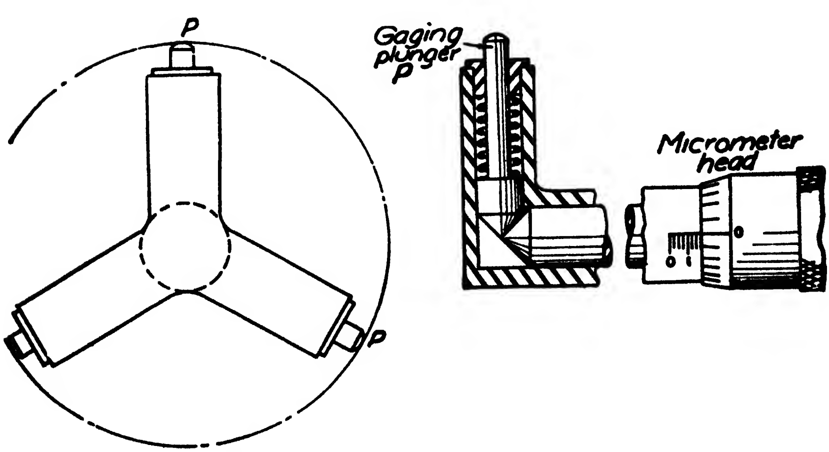


FIG. 17-17. Star Gage for Three-point Measurement of the Diameters of Deep Holes.

227. Visual gages are used for mass-production inspection, particularly for such elements as screw threads and parts for selective assembly. Fig. 17-21 shows a **visual gage** for inspecting and classifying cylindrical parts. The parts are rolled on the lower anvil, under the spindle, or upper gaging member, which has a diamond point. The vertical deflection of the spindle is magnified by a system of steel reeds and is read on the scale at the top of the instrument. The lower gaging anvil is in two parts which have tapered contact surfaces. The instrument is set for a basic size by turning an adjusting screw, as indicated, which causes the upper part of the anvil to move to the right or left, and thereby changes the vertical distance from the top of the anvil to the point of the spindle. *Master gage blocks* are generally used, as illustrated, for setting the anvil to the correct position for a particular inspection operation.

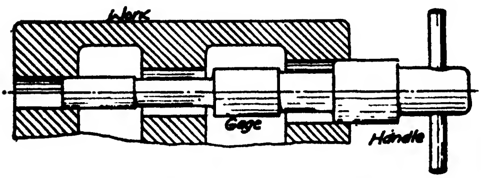


FIG. 17-18. Alignment Gage.

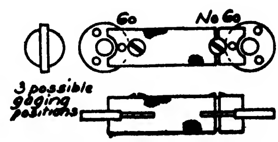


FIG. 17-19. Woodruff Keyseat Gage.

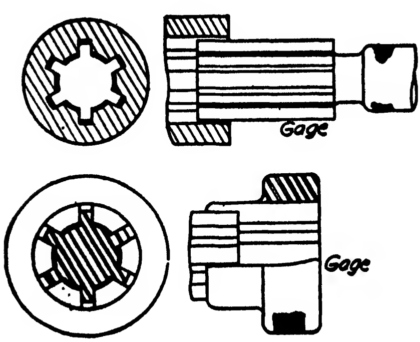


FIG. 17-20. Spline Gages.

Gages with **magnification ratios** of 500:1, 1000:1, and 10000:1 are commercially available. Each figure on the scale at the top of a 10000:1 magnification instrument indicates a variation of .0001″, and it is therefore possible for comparatively unskilled operators to detect minute differences in the diameter or height of parts. The gage is extensively used for classifying parts for selective assembly, although the parts may have been produced by the aid of commercial snap or ring gages.

Special attachments may be applied to these gages so that internal diameters and angles may be inspected.

Fig. 17-22 shows a **visual limit gage** for determining whether a diameter or a length is within given limits. The instrument may be set for two limiting dimensions by using master gage blocks. When a part

that is within the maximum and minimum limits is placed on the anvil and moved underneath the gaging point of the spindle, an amber light shows in the lens at the top of the instrument. If the part is over the maximum limit, a green light appears; if undersize, a red light is seen. This gage may be set for any tolerance from .00005″ to .012″. The accuracy of the gage itself is within .00001″ within any setting of the instrument.

Electrical limit gages that incorporate a number of gaging points so that every critical dimension of a part may be simultaneously checked are

Ford Motor Co.

FIG. 17-21. Setting a Visual Gage with Johansson Gage Blocks.

Sheffield Gage Corporation

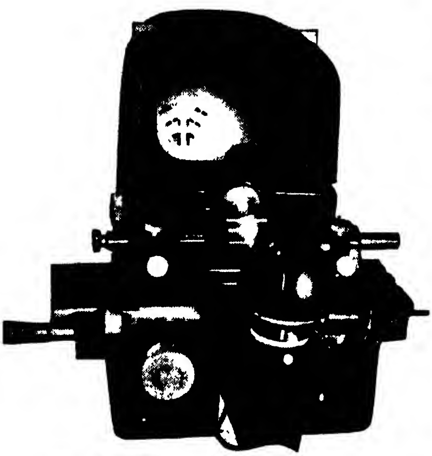
FIG. 17-22. Electrical Limit Gage.

also available. Limit gages that operate by means of compressed air or other fluids are also used in mass-production gaging operations.

228. Contour measuring projectors are optical projection machines for accurate and rapid inspection of screw threads or other irregular profiles. The machine table may be adjusted or set in three planes, and the part to be inspected is held by a suitable fixture or a set of centers. The light rays pass from the lamp across the work through a microscope to a mirror, from which they are reflected on a translucent chart.

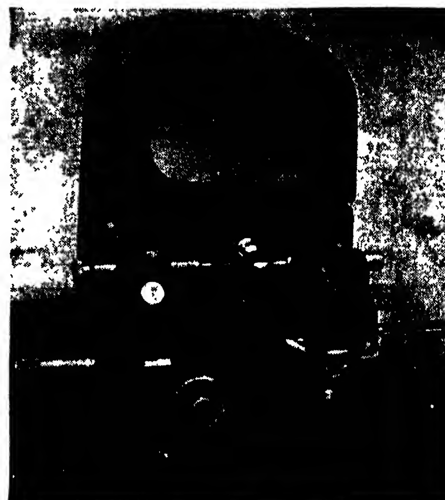
Machine equipment for inspecting screws and taps consists of a fixture in which the part to be inspected is held, a master gage with which the

work is compared, and tolerance charts on which the shadow of the thread is projected for comparison. The machine is adjusted by staging the master gage in the fixture, and the shadow of the master thread brought to coincide with the upper tolerance outline on the chart illustrated in Fig. 17-23. The master gage is then replaced by the production screw to be checked. To pass inspection, the shadow of the production thread must fall between the upper and lower outlines of the chart, since the space between these outlines represents permissible tolerance for the class of fit required. Lateral



Jones & Lamson Machine Co.

FIG. 17-23. Screw Thread Comparator Used for Thread Hob Inspection.



Jones & Lamson Machine Co.

FIG. 17-24. Contour Measuring Projector.

displacement of the shadow indicates lead error; vertical displacement shows pitch diameter variation.

For measuring thread leads or other types of spacing, a micrometer, shown at the left in Fig. 17-24, is used for moving the table and work before the lens. In this way spacing may be checked from tooth to tooth or over a distance of one inch or any fraction thereof.

Such diverse parts as forming rolls for hookless fasteners, teeth of saw blades, try-squares and threading tools are quickly inspected on these machines and permit comparatively unskilled labor to pass judgment on their accuracy.

CHAPTER 18

PRODUCTION CASTING PROCESSES

229. Mass-production casting processes differ from unit-production processes in several important respects. Foundry operations are carefully planned and supervised, instead of being dependent upon the skill of the individual operator; labor-saving machinery is used wherever practicable; and special patterns and other devices are extensively employed to facilitate production and accuracy.

Except for very large castings, most of the patterns used in the production foundry are made of metal, either cast iron or brass. Many **metal patterns** are made in the machine shop but some metal patterns are produced in the foundry. In making a wooden pattern for a metal pattern, the patternmaker is careful to include a double shrinkage allowance —one for the metal pattern and one for the casting—in order that the final foundry product may be of correct size.

230. Matchplate molding is extensively used in mass-production foundry work. Fig. 18-1 shows a mold for a flat-belt pulley, in which both the cope and the drag are made with the same matchplate. The **matchplate** *M* is a flat metal plate with two or more locating pins *L*, to which a pattern for one-half the pulley is fastened (or the pattern may be integral with the plate, as illustrated). The matchplate has a **runner pattern** *R*, which also supports a **loose gate pattern** *G*. (A mold of this character would probably require a riser as well, but the riser pattern is omitted for the sake of clarity.) In molding, the drag would be made first with the gate pattern *G* removed. The drag is placed over the locating pins *L* and is filled with sand which is rammed, strickled off, and vented. The drag is rapped and inverted and the matchplate is drawn. The cope is then placed on the matchplate and the gate pattern *G* is put in place as illustrated. The cope is then filled with sand which is rammed, strickled off and vented. The cope is rapped and the gate pattern is drawn; the cope is then inverted, and the matchplate is drawn. The cope is then reverted and placed on the drag after the core has been set in place. This procedure contrasts very favorably both in labor costs and results with the procedure necessary in making a similar mold with a two piece plain pattern.

Fig. 18-2 shows how four cast iron pipe tees may be produced in one molding procedure. This arrangement of parts is known as a **spray pattern plate**, and includes solid gate, riser and runner patterns in

the cope plate. Fig. 18-3 shows a mechanic filing and finishing a spray pattern for six pintle chain links. The large and small cylindrical bars through the ends of the links are used to produce core prints in the mold to serve as a seat for the cores for the chain pin holes.

Matchplates may be made of cast iron or brass, and are often cast from a wooden pattern. Fig. 18-4 illustrates two matchplates made of Super Tamastone, a cement which when mixed with water hardens to a stone-like character in an hour. The right figure shows a spray of six parts, which is made from six loose metal patterns set into a metal frame and fixed by pouring the cement around them. This matchplate is used to make the drag matchplate, left, by molding it in sand and pouring in the cement. After the cope plate has been used for making the drag pattern, the runners shown between the parts are

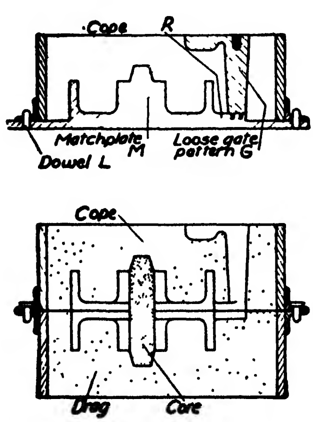


FIG. 18-1. Molding a Pulley with a Cored Hole, Using a Matchplate and a Loose Pattern.

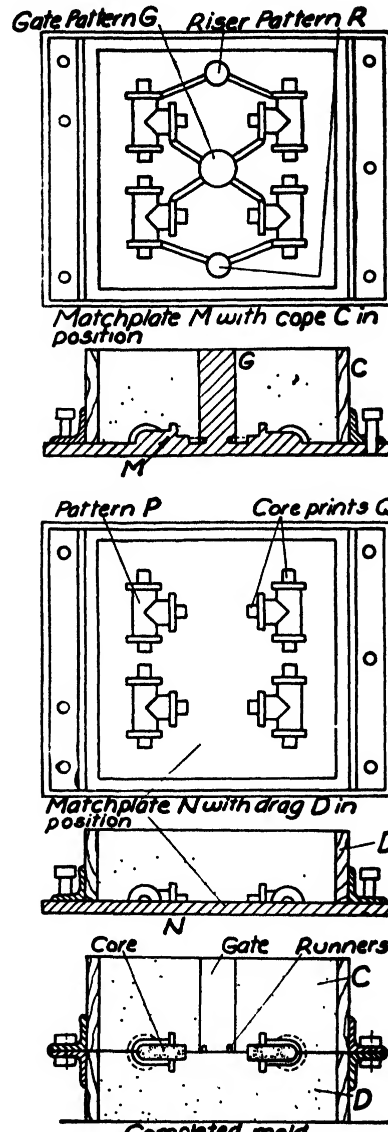
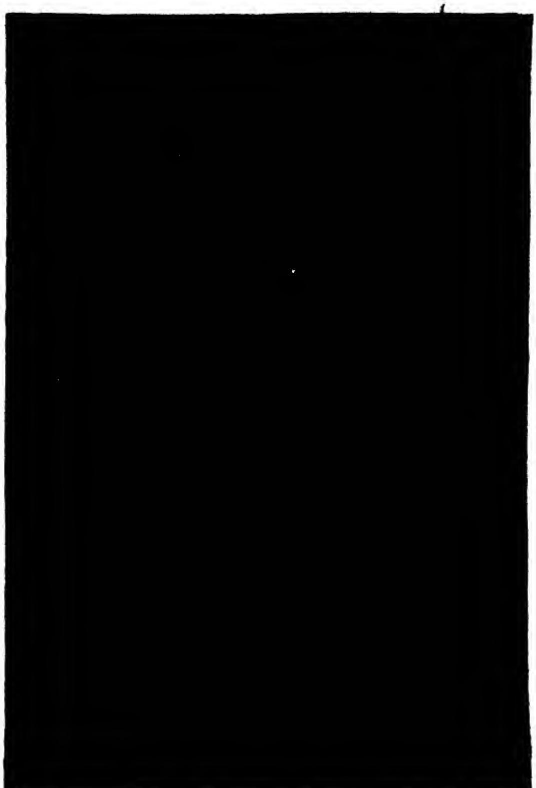


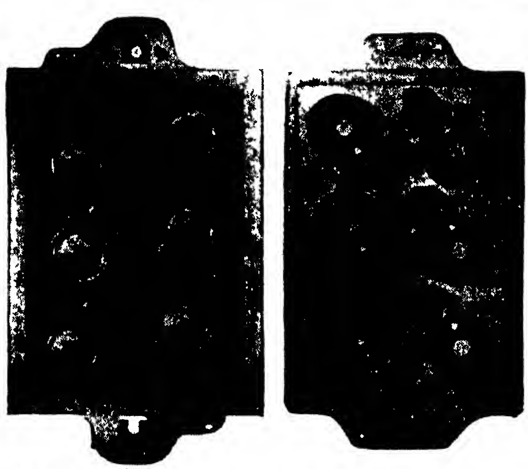
FIG. 18-2. Matchplate Molding.

made of cement and added. Fig. 18-5 illustrates a Tamastone matchplate made from three loose patterns by using these patterns to make a mold first



Chain Belt Co.

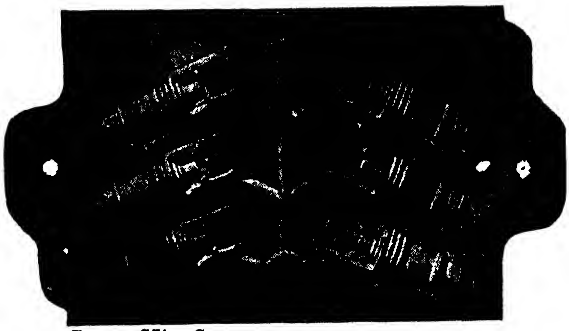
Fig. 18-3. Filing a Spray Pattern for Six Pintle Chain Links.



Tamms Silica Co.

Fig. 18-4. Cope and Drag Matchplates.

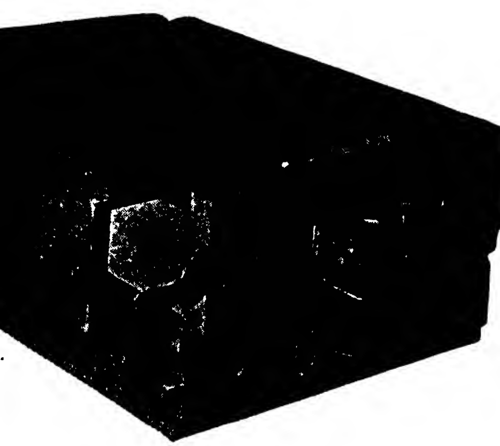
on one and then on the other side of the matchplate frame. The gates and runners are added by hand; the illustration clearly shows the detail of this handiwork.



Tamms Silica Co.

FIG. 18-5. Cope Matchplate.

231. Fig. 18-6 illustrates the cope and drag portions of a **removable snap flask.** After the mold has been made and placed upon the foundry floor ready for pouring, the snap flasks are removed from the mold by



Tabor Mfg. Co.

FIG. 18-6. Snap Flask.

unlatching one corner, and are replaced by a metal slip jacket which is slipped over the mold. Since slip jackets, which have sheet steel sides and are open at top and bottom, are much cheaper than flasks, the snap flask can be in continuous use and serve for many molds during the day.

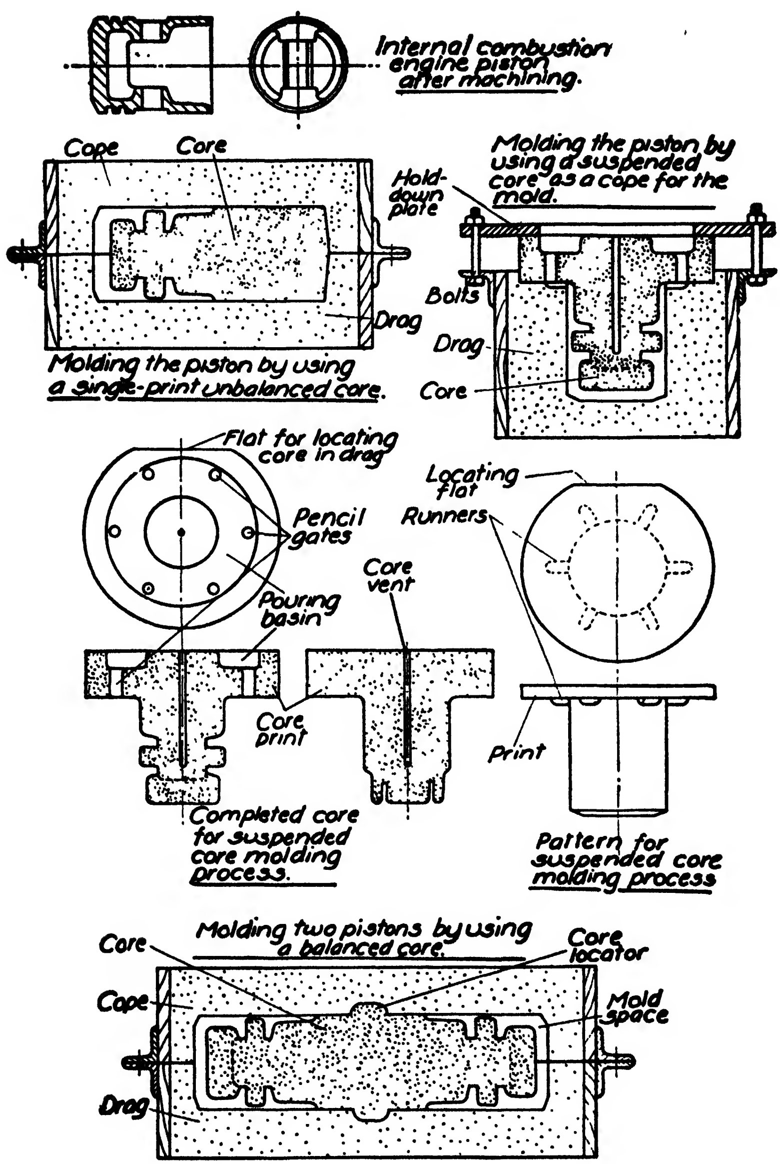


FIG. 18-7. Methods of Molding an Internal Combustion Engine Piston.

232. Fig. 18-7 illustrates several methods of molding an internal combustion engine piston. The smallest flask, and consequently the minimum volume of molding sand and the least expensive core, are required when a **single-print unbalanced core mold** is used. The core is difficult to set and hold, however, and the casting may have uneven wall thickness. The **balanced core method** producing two castings simultaneously is much more efficient. The third method shown, which uses a **suspended core** as the mold cope, gives better castings since the pencil gates afford an even distribution of metal. The core is, however, more expensive to make than either of the others. In each of these processes it should be observed that the core for the piston pin hole does not extend to the outer wall of the casting. This is done to prevent damage to the mold when the core is set, and leaves a thin wall of metal at the hole which can, however, be easily removed in machining.

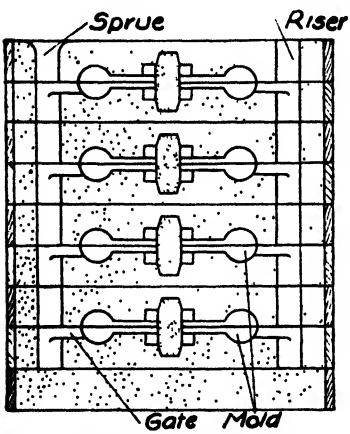


Fig. 18-8. Stacked Mold.

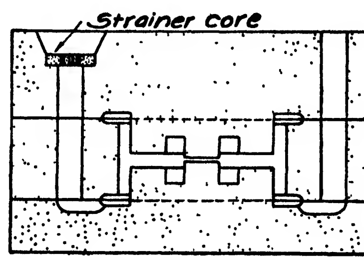


Fig. 18-9. Dry Sand Core Mold.

Fig. 18-8 illustrates a vertical or **stacked mold** in which four (or more) small handwheel castings are obtained at one pouring. This type of mold requires less floor space than a spray pattern mold for a like number of parts, and produces better castings for some types of work. The molten metal is poured into the sprue, and rises, filling each mold space in turn. In this way a continual supply of metal at the correct pouring temperature is furnished to each mold, and there is little danger that the metal will cool as it flows along the runners, which may happen in spray pattern molding. Stacked molds may be entirely composed of dry sand cores which can be made on a production basis in the core room, so that all that has to be done on the foundry floor is to assemble the cores and clamp them together. One manufacturer uses a stacked mold for producing cast steel crank shafts for automobile engines. Fig. 18-9 illustrates a mold for a flanged pulley, which is made up of **three major dry sand cores** and a **strainer core.** The strainer core is made of dry sand and

has a series of small holes in it to separate the solid masses of slag from the molten metal.

Dry sand cores for mass-production molding are made in core boxes, into which the sand is rammed by a jolting or jarring process essentially similar to jolt ramming for mold making. Core blowing machines deliver the core sand mixture by air at high pressure into core boxes which are clamped in position on the machine. Cores of uniform section are produced on another type of machine by forcing the core-sand mixture through a die by means of a conveyor screw. Cores of any length from ⅜" to 3" in diameter are made in this manner, with a vent through the center of the core. The cores are then baked on trays in a core oven. Cores of intricate shape are often vented by incorporating strips or "wires" of wax in the sand during their preparation. The wax melts as the cores are baked, and vents of suitable size are therefore left in the cores.

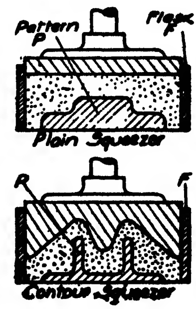


FIG. 18-10. Squeezer Machine Principles.

233. Many foundry operations, particularly in mass-production, are performed by the aid of **molding machinery.** There are three important operations in which molding machines are used: ramming the sand, drawing the pattern, and turning over the completed mold.

234. The **squeezer machine** operates on the principle of a press, since the mold is rammed by forcing a squeezer board against the sand which covers the pattern in the flask. The squeezer machine is used for shallow patterns because the sand near the squeezer board is most effectively compressed. For deep draws, a **contour squeezer** is sometimes employed. Squeezer machines may be hand operated by using a system of levers to obtain the desired pressure, but modern molding machines generally use compressed air within cylinders for actuating the squeezer platen.

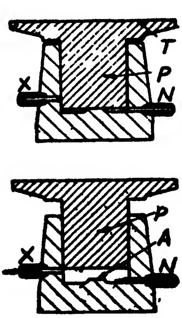


FIG. 18-11. Jolt Ramming Machines Principles.

Sand is rammed into molds by a jarring or jolting action obtained by raising the pattern mount, flask, and sand, and allowing them to fall on a solid foundation. The **jolt rammer** generally consists of a piston within a cylinder as illustrated in Fig. 18-11. The mold is fastened to table *T* which is integral with piston *P*. Compressed air is admitted through the intake pipe *N*, which raises the piston until it overruns the exhaust port *X*, which permits the air to escape and allows the piston to fall and strike the anvil *A*. The cycle is repeated until the sand in the mold has attained the desired

density. Plain jolt machines are built to operate with a stroke from 1" to 2" in height, and at a rate of 120 to 250 blows per minute. In a jolt-rammed mold the sand is not well compressed at the top. This portion of the mold may be rammed by hand, termed *butting off,* or the ramming may be completed in a squeezer machine.

"Shockless" jolt machines are used where vibration and shock are undesirable, and incorporate a movable anvil which is supported on springs, and which moves upward at each fall of the jolt piston. The effect of the blow is therefore utilized almost entirely for packing the sand without transmitting any great amount of shock or vibration to the machine and its foundation.

In hand molding, molders often fill corners which are more or less inaccessible to ramming by throwing compressed handfuls of sand intc place. **Sandslingers** are molding machines that operate on this principle. Molding sand is delivered by a belt conveyor or scraper to an oscillating screen which sifts out undesirable material. The sand is delivered to a hopper, from which it is carried on a belt conveyor to the head of the machine, which contains a rotating impeller wheel to which one cup-shaped blade is attached. The sand is thereby compressed into wads which are thrown with considerable force into the mold through an outlet in the bottom of the head of the machine. The head is carried on an arm which is generally moved by hand so as to direct the deposition of sand wherever it is required. The machine may be adjusted to vary the ramming to suit any molding condition required. The sandslinger rams the sand uniformly over the total area as well as the height of the mold, and does not damage the pattern in the process.

Several types of sandslingers are built to take care of varying foundry conditions. The stationary type is fastened to the foundry floor and is used in production foundries which have auxiliary sand-handling equipment for supplying sand to the sandslinger. The tractor type is built to travel on tracks, and collects sand from the foundry floor. The portable sandslinger is transported to any location in the foundry by an overhead crane. It is generally placed near the scene of the molding operation, and the sand is shoveled to the base of the machine from which it is delivered to the screen by a vertical bucket conveyor.

235. Pattern draw machines are used to enable the pattern to be removed without damage to the mold. They are particularly useful in drawing large, deep patterns of intricate form, and in work involving match-plate sprays, since the machines facilitate precise parallel drawing which is often difficult to obtained when the patterns are hand drawn. Pattern draw machines may be hand-actuated by means of a system of levers, or they

may be operated by compressed air within a cylinder. Fig. 18-12 illustrates the principle involved in **plain drawing.** The flask is located by means of pins on the machine table, and is lifted by rods R after the mold is filled and rammed. This machine is used for shallow draws, and machines are generally used in pairs for simultaneous handling of the cope and drag.

For deep molding, the **rollover table machine** illustrated in principle in Fig. 18-13 has some advantages. The pattern and matchplate are attached to the rollover arms A which can rotate on trunnions T in the draw bracket B. The flask F is filled, rammed and strickled, and a bottom board

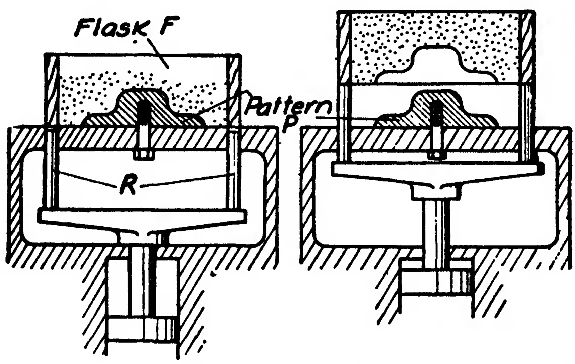


Fig. 18-12. Principles of Plain Pattern Draw Operations.

D is placed on the flask and clamped to A by clamps C. The arms are then rotated through 180° until the bottom board rests on the cradle P. The clamps are disengaged, and the draw bracket B rises vertically to draw the pattern N; the rollover arm is returned to its initial position and the completed mold is removed from the cradle. An advantage of this type of machine is that it can be kept continuously at work, since the completed mold can be removed by helpers while the molder is ramming up a new mold at the right. The occupation of the cradle by the completed mold does not interfere with the operation of making a second mold. Simple rollover draw machines are often portable as illustrated.

Machine molded patterns must be **rapped** before drawing in order to free the pattern from the sand. In some of the plain machines rapping is performed by the molder with a wooden mallet. In other molding machinery the rapping is accomplished by a **power-driven vibrator** applied to the matchplate, which is thus vibrated independently from the rest of the machine. The vibrator consists of a long double-acting piston with a stroke of about $\frac{5}{16}$", working automatically in a cylinder with hardened

anvils. and striking about 5000 blows per minute. Compressed air is used to actuate the vibrator piston.

Rapping may cause the mold impression, and consequently the casting, to be appreciably larger than the pattern. To overcome this defect, patterns may be drawn by the **stripping plate method** illustrated in Fig. 18-14. The stripper plate *S* has a hole which fits the pattern contour at the parting line. The mold is rammed up in exactly the same manner as the plain pattern, but when the pattern is drawn the stripper plate remains in place and supports the sand at the surface of the mold joint. The pattern need not be rapped, and as delivery takes place in a perfectly straight line, the mold is exactly pattern size. Stripper plate drawing is adapted to fragile molds which have deep parallel sides, but the equipment is much more expensive than plain pattern drawing equipment. The stripper plate must fit the pattern very closely in order to provide effective support, and must therefore be renewed whenever sand causes wear or deterioration. In some instances, stripper plate stools, shown by *T* in Fig. 18-14, are used for sand masses that cannot be carried on the stripper plate itself.

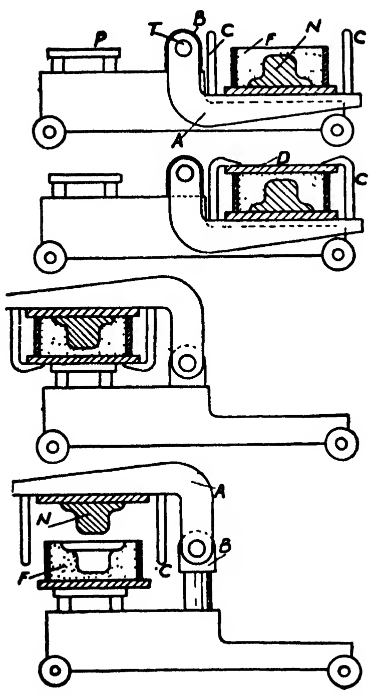


Fig. 18-13. Principles of Portable Rollover Draw Machine Operation.

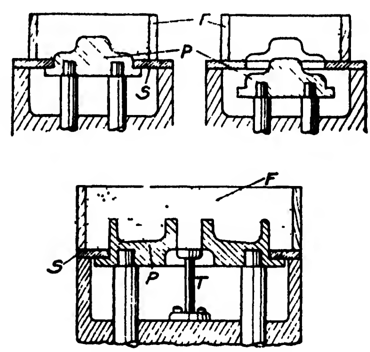


Fig. 18-14. Principles of Stripper Plate Draw Operations.

236. Fig. 18-15 shows a **combination jolting-squeezing-stripping molding machine,** and Fig. 18-16 illustrates the principle of operation. A matchplate *M* is placed on the pattern table *T* which is fastened to the jolter piston *J*. The stripper plate *S* is located on the matchplate and a cope

F is located on the stripper plate. The cope is filled with sand which is rammed by jolting. After the sand has been rammed, the air supply to the jolting piston is cut off and air is admitted underneath the squeezer piston Q, thereby lifting the flask, stripper, matchplate, and pistons J and Q. The squeezer board B, which is attached to the squeezer plate P, and which has been previously adjusted for height and position by the screw W in arm A, fits into the flask and squeezes the sand in the flask to final density as the piston Q moves upward. Meanwhile, the pistons C have lifted the stripping frame R to the position indicated. When the squeezing operation is completed, piston Q descends until S rests on the stripper frame R, which is held at its upper position by the air pressure under the pistons C. The piston Q carries the matchplate with it until the pattern is clear of the mold. The arm A is then swung out of the way and the finished cope F is removed. The stripper frame R then descends until it rests in its original position, and another flask is placed on the stripper plate S.

Milwaukee Foundry Equipment Co.

FIG. 18-15. Jolt Squeezing Stripper.

The molding machine shown in Fig. 18-15 has a pattern width of 16″, a draw of 8″, a lifting capacity in jolting of 1500 pounds, and a total squeezing pressure of 12,000 pounds. The jolt-squeezer is generally used for cope filling since it is not necessary to turn the copes over in preparing them for the foundry. The matchplates are often equipped with loose-piece gates and risers.

Fig. 18-17 illustrates a power jolt-rollover-draw molding machine which rams the sand by jolting, rolls the flask over, and draws the pattern. The operating principles of the machine are illustrated in Fig. 18-18. The first stage shows the flask F bedded down on the matchplate M, which is located on the pattern table Q, which rests on the jolting head H. The sand is rammed by jolting, and the swinging arms A that carry the clamps C

are swung over the flask which is covered by the bottom board B. As the clamps C move downward, the rollover arm D is brought up slightly and locks automatically to the pattern table Q, so as to clamp the pattern table Q,

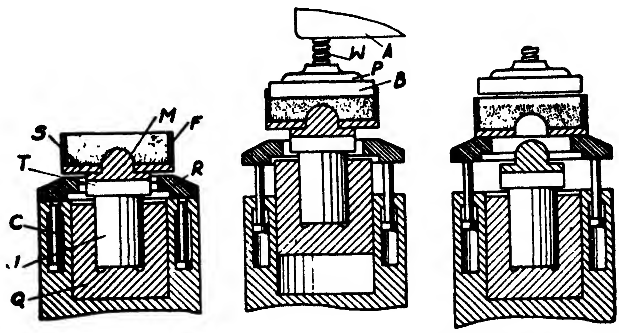


FIG. 18-16. Operation of Jolt-squeezing Stripper.

flask F, and board B between the arm D and the clamp C, as illustrated in the second stage. The entire unit then rotates through 180° about the axis of two trunnions, bringing the bottom board to rest on the equalizing pins P

Milwaukee Foundry Equipment Co.

FIG. 18-17. Power Jolt-rollover-draw Molding Machine in Operation.

of the draw table L. The clamps C are then released and swung out of the way, and the draw table descends, drawing the mold from the pattern and matchplate M, which remains clamped to D. The bottom board finally

rests on the roller conveyor *R*, and the rollover arm swings back to its original position completing the molding cycle. The jolting, clamping, rollover, and drawing operations are controlled by compressed air valves.

237. Continuous conveyors are extensively used in mass-production foundries. Fig. 18-21 illustrates the pouring zone of a continuous mold conveyor. The molder receives sand from overhead hoppers, and the molds are made and placed on the conveyor on which they travel to the pouring zone illustrated. The molds are then carried through a cooling

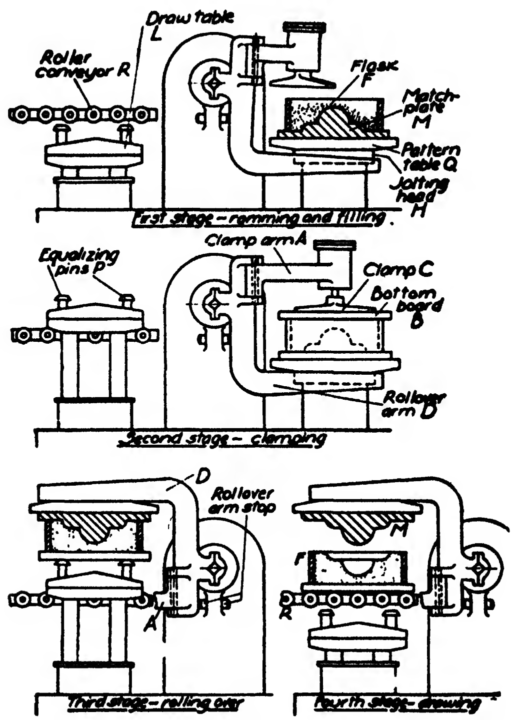


FIG. 18-18. Operation of Power Jolt-rollover-draw Molding Machine.

tunnel to a vibrating shake-out screen where the mold sand is discharged into a bin. The old sand is reconditioned and carried by a belt conveyor to the hoppers where it is used again. The empty flasks are returned from the shake-out to the molders' station by another conveyor.

238. In mass-production foundry operation, the question of **proper gating** is no longer within the province of the individual molder. Molds for mass-production should be designed with the same care that fixtures and tools for machining operations are planned, especially when the complexity

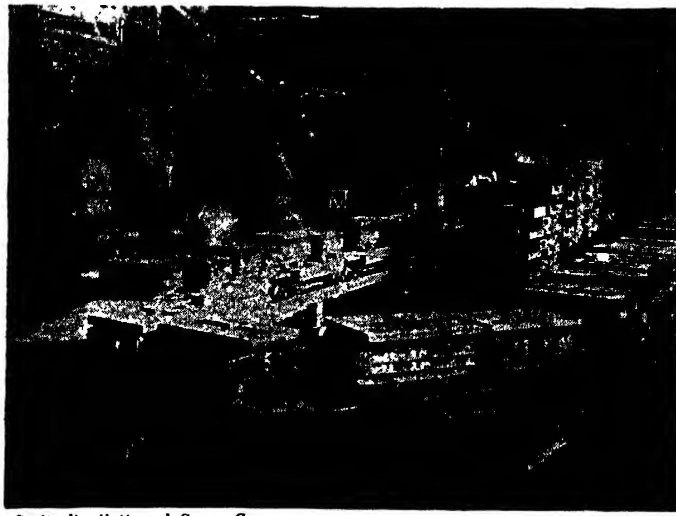
Milwaukee Foundry Equipment Co.

FIG. 18-19. Removing a Cope from a Matchplate.

Chrysler Corporation

FIG. 18-20. Molds for Engine Cylinder Blocks in the Process of Assembly on a Conveyor.

of modern castings and the very low percentage of *rejects* or defective castings are considered.



C. O. Bartlett and Snow Co.

FIG. 18-21. Pouring Zone of Continuous Mold Conveyor.

Fig. 18-22 is an example of gating **redesign** that eliminated a rather high percentage of rejects. The part to be cast is a 4″ nickel silver check valve. As originally designed, the mold was gated as indicated by the solid lines, and the metal poured at a temperature of 2750° F. Section *AA*, above, illustrates the shrinkage that developed in many of the castings. The dotted lines show how the mold gating was redesigned to effect a better distribution of the molten metal. Castings poured at a somewhat lower temperature—2500° F. to 2600° F.—were found to be pressure-tight and quite satisfactory.

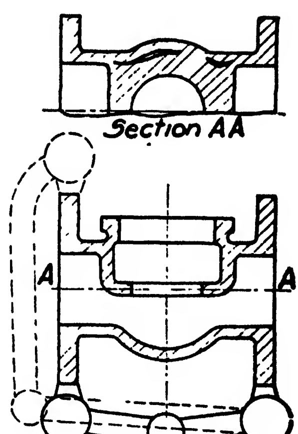
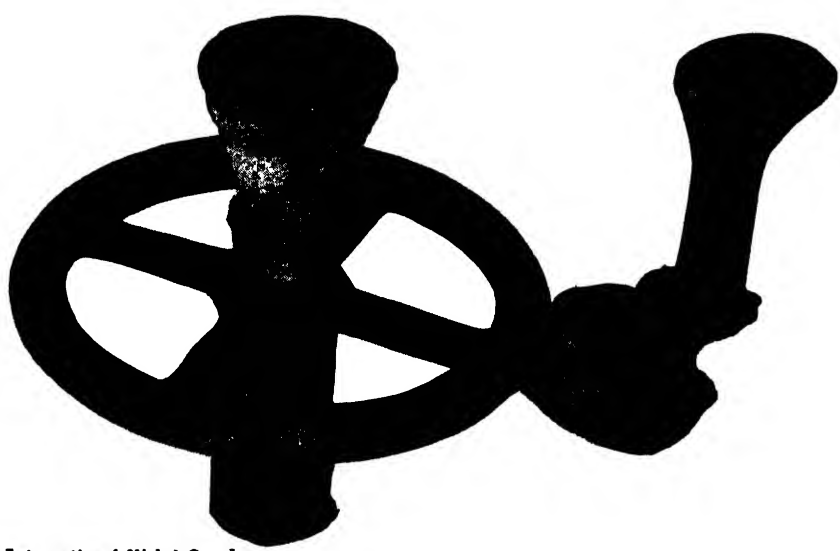


FIG. 18-22. Alternate Gating Methods for a Check Valve Body Casting.

Fig. 18-23 illustrates a 20% nickel silver handwheel as cast. Heavy gate and riser sprues are used for this material, and an enlarged gate is used near the rim of the wheel so that dross or slag in the molten metal may float to the top and be trapped. The depression at the top of the riser shows how this sprue acts as a feeder for the interior of the casting as it cools and shrinks.

It is an axiom among foundrymen that the most important portion of a casting should be placed at the *bottom* of the mold because the slag will rise to the top of the mold space as the casting is poured, and also because the lower portion of the casting is subjected to the greatest pressure head, and is therefore the soundest and densest part of the casting. This is another reason why the **suspended-core** method of molding the piston of Fig. 18-7 is preferred to the other two methods shown. For some piston castings in which it is necessary that every portion of the casting shall be sound, the suspended-core method is used, but the skirts of the



International Nickel Co., Inc.

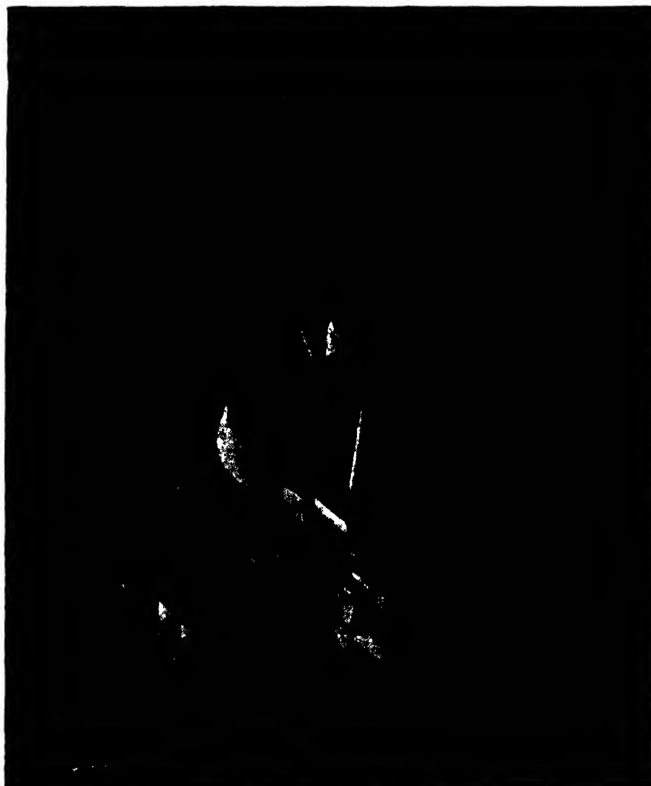
Fig. 18-23. Handwheel Casting.

piston casting are made one or two inches longer than necessary, so that the end of the skirt will contain any slag or foreign material that is present in the molten iron. The excess skirt length is cut off in the subsequent machining processes, thereby disposing of any slag-impregnated metal.

239. Permanent molds are those which may be used repeatedly for identical castings. The mold is not destroyed in the process of removing the casting as is the case with single-purpose sand molds. Permanent molds are used for ferrous and non-ferrous metal castings and for plastic molding. There are three important forms of permanent mold casting; slush casting; gravity feed or permanent mold casting; and die casting.

240. A slush casting is a hollow casting formed in a metal mold without the use of cores. The molten metal is ladled into a chilled mold

to its full capacity; the mold is immediately inverted and the liquid interior of the casting is poured or *slushed* out, leaving a thin-walled casting whose outer surface has been solidified by the inner surface of the mold. An alloy of zinc with 15% antimony is generally used in the process, which is extensively employed for the manufacture of candlesticks, toy soldiers and metal novelties.



"Aluminum" by Hobbs, Bruce Publishing Co.

FIG. 18-24. Pouring an Aluminum-alloy Permanent-mold Casting.

241. Gravity feed or permanent mold castings are formed in a metal mold in which the casting metal is subjected to the force of gravity. The process is essentially analogous to sand casting but the completed castings are more accurate than sand molded products, although not as accurate as die-cast parts. The process is adapted to castings in which excellent metallurgical structure is essential, but should not be employed for intricately-shaped or very thin parts. The process is extensively employed in the manufacture of aluminum pistons requiring subsequent heat treatment and

in miscellaneous small parts in aluminum bronze. Fig. 18-24 illustrates the pouring operation in the manufacture of an aluminum alloy permanent mold casting. The mold is parted in a vertical plane. At the rear of the foundryman there is a crucible pot furnace for melting the alloy.

Many small iron parts are cast in **permanent mold machines.** In the machine shown in Fig. 18-25, twelve air-cooled molds are mounted on a rotary conveyor. The molds are made of cast iron, are parted vertically, and are mounted so that they can be conveniently opened and closed by compressed air cylinders. The interior of the mold is faced with a thin layer of refractory material, and a deposit of carbon is placed on this coating by means of a pair of acetylene gas pipes G to protect the mold

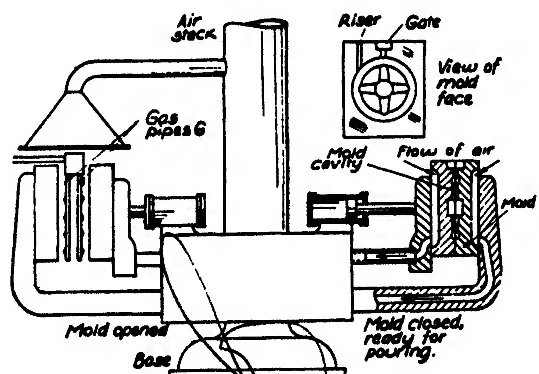


FIG. 18-25. Metal Mold Casting Machine.

surfaces against the abrasive action of the molten metal. Pouring is done through short gates and the mold is opened to eject the casting as soon as the molten metal has set. The surfaces of the mold are cleansed with air, recoated with carbon, and allowed to cool for a short time before being closed again. These molds may be used for an average production of 15,000 castings. Practically all iron castings made in metal molds are annealed to improve their machineability.

242. Die castings are produced by forcing molten metal under pressure into a steel die. The pressure is maintained until solidification is complete. The process is essentially a further development of gravity-feed casting, but the **pressure function** entails finer detail and better finish. While gravity-feed casting tonnage is greater than that of pressure casting, the latter has a wider field of application and is more important in the quantity production of precision parts. Zinc alloys are generally used for die castings, although aluminum alloys, brass alloys and other non-ferrous metals are used to a considerable extent.

The process of die casting is entirely automatic and requires the following **elements**: a die casting machine to hold the molten metal under pressure; a metallic mold or die capable of receiving the molten metal, and designed to permit easy and economical ejection of the solidified product; and a casting alloy that will produce a satisfactory product with suitable physical characteristics.

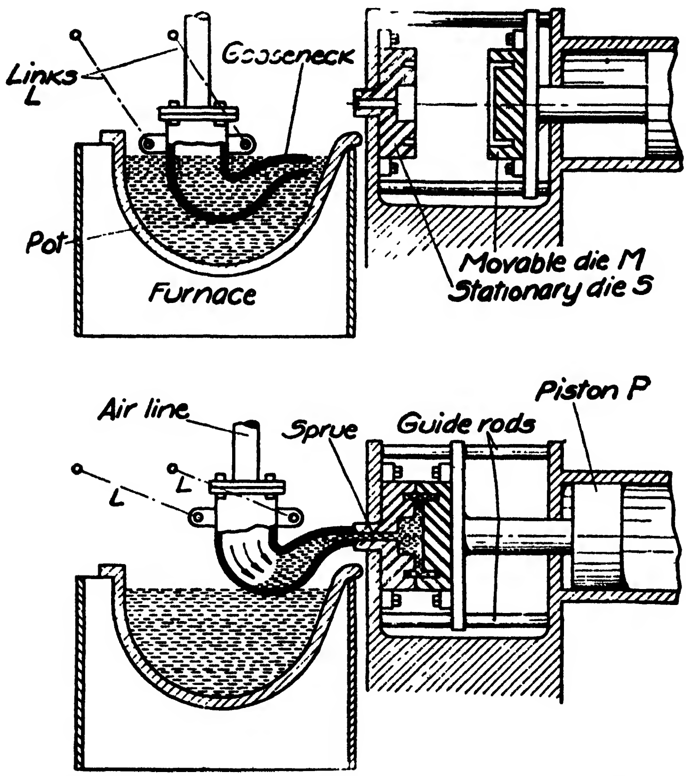


FIG. 18-26. Operation of Air-operated Die-casting Machine.

There are two types of **die casting machines**: the first forces the material into the die by high pressure on the surface of the molten metal in a special ladle or goose; and the second forces the material into the die by means of a cylinder and piston which are submerged in the molten metal. The **air-operated machine** is illustrated in principle in Fig. 18-26. The molten metal is contained in a pot which is heated by a surrounding furnace. The ladle or *goose* is carried on two links L, which permit it to be submerged in the metal for filling. The links then swing the goose up to the die nozzle

and compressed air at a pressure of approximately 500 pounds per square inch acts on the surface of the metal in the goose, forcing the molten metal through the die sprue into the die. The machine illustrated is equipped with dies for casting a small flat belt pulley, and the dies are opened and closed by an air-actuated piston P in a cylinder.

Fig. 18-27 illustrates a **plunger-type die-casting machine** in which the molten metal is forced into a vertical sprue at the parting line of the dies. The cylinder and piston are submerged in the pot, and the cylinder

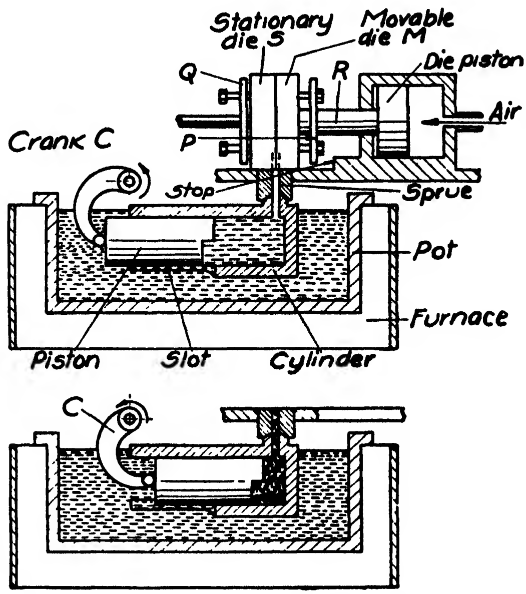


FIG. 18-27. Plunger-type Die-casting Machine.

is slotted to permit the entry of the molten metal as the piston recedes. The forward motion of the piston closes the slot and forces the metal into the die. The piston is actuated by a crank which is connected to a lever in hand-actuated machines, or by a crank, connecting rod, and piston in air-actuated machines.

243. Figs. 18-28 to 18-32 illustrate the action of a **die and die carriage.** Fig. 18-28 shows the first stage with the die closed, the ejector pins E retracted, and the core pins F and D in place ready to receive the charge of molten metal in the mold space V. The second stage shows the die after the metal has solidified. The core-retracting plate Q has been drawn back, removing the cores from that portion of the casting in the stationary half S of the die. The third stage, Fig. 18-30, shows the movable

half M of the die moving to the right and thereby partially opening the die. In the next stage the die is shown completely opened. The ejector pin plate P is rendered stationary by a stop (illustrated in Fig. 18-27) and the pins E project through M to force the casting off the die and core pins.

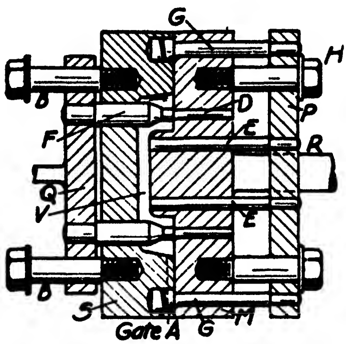


Fig. 18-28. Die-casting Mold Operation—Stage 1.

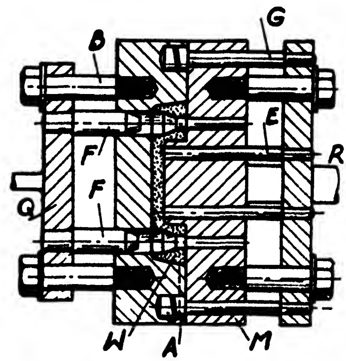


Fig. 18-29. Die-casting Mold Operation—Stage 2.

The fifth stage, Fig. 18-32, shows the movable half M of the die moving to the left, thereby closing the die, while core-retracting plate Q is at the same time moving to the right to attain the position illustrated in Fig. 18-28. The bolts B act as stop screws for Q; the bolts H serve to bring the plate P

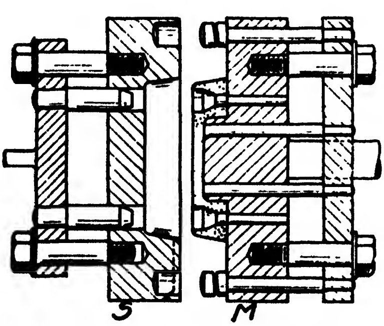


Fig. 18-30. Die-casting Mold Operation—Stage 3.

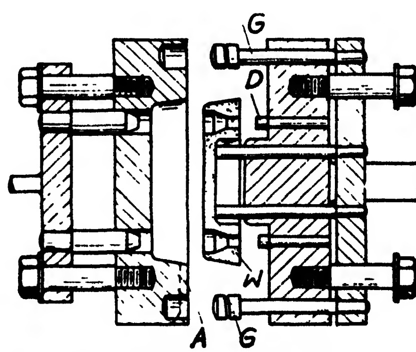


Fig. 18-31. Die-casting Mold Operation—Stage 4.

into position as the die closes; and the guide pins G serve to align the two die halves properly, and prevent any side displacement as the molten metal enters.

244. The dies shown in Figs. 18-27 and 18-28 are known as **split-sprue gated frame dies,** since the metal flows into the die at the part-

ing line. The die shown in Fig. 18-26 is a **solid-sprue gated die** because the metal enters through the solid back of the stationary die. The split-sprue die is advantageous for shallow die castings since it affords a short, direct flow to the die cavity. The solid-sprue die is adapted to ring castings that can be gated in the center, and also to deep castings where a center gate balances the metal flow. The solid-sprue die is the most extensively used.

Die casting dies are constructed in different styles for various production requirements. A **single die** contains an impression of only one part; a **multiple die** contains two or more impressions of any one part; a **combination die** contains one impression only of two or more parts; and a **combination-multiple die** contains a number of impressions of each of two or more parts. Single dies are comparatively cheap and are used for small-lot production, since they reduce the tool investment to a minimum for any one part. Combination dies, when properly planned, will reduce the total die cost for a given set of castings to a minimum. They are applicable to parts that will always be used in the same quantities and of the same alloy. These parts should be of the same general character and weight. Multiple dies are usually slower to operate than single dies but will give higher production rates for the same labor costs.

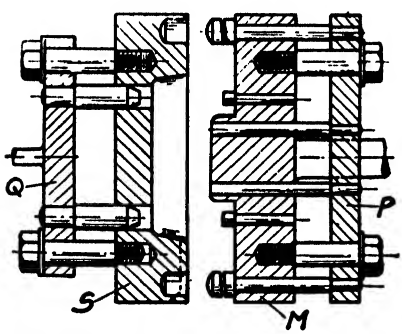


FIG. 18-32. Die-casting Mold Operation —Stage 5.

Die-casting dies are often vented by permitting air to escape through the clearance in the ejector and core pin bearings. The problem of venting is considerably more important than in sand casting because the mold has no porosity. Sometimes dies are vented by grinding shallow grooves on the parting surfaces of the dies; in other instances plugs with suitable vent grooves are added to the die.

245. Plastic molding is analogous to die casting in many of its forms. Plastic molding is a **pressure process** which is performed either in hydraulic presses with ram capacities of 1000 to 3000 pounds per square inch, or in special injection molding machines.

246. Fig. 18-33 illustrates the principle of operation of an **injection molding machine** for Tenite, a cellulose-acetate plastic. The material, in granulated form, is placed in a feed hopper and forced past a **spreader** through a nozzle into a water-cooled multiple die by a reciprocating plunger. The material is heated to a plastic state as it passes through the injection

head. Fast production is the primary advantage of injection molding; the machine shown operates at four cycles per minute, and will attain a produc-

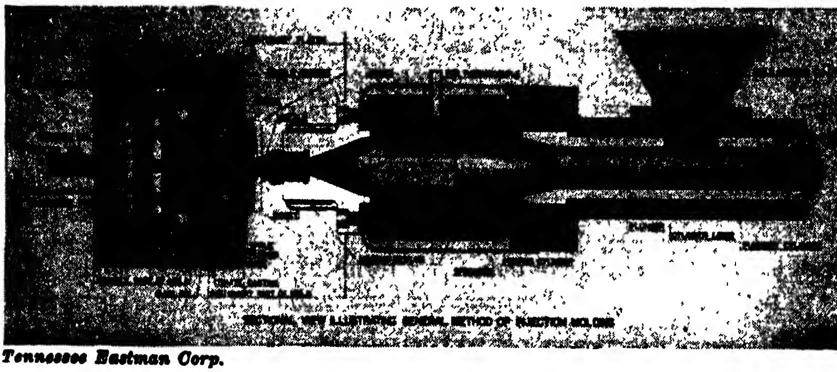


FIG. 18-33. Injection Molding.

tion rate of 480 parts per hour while using the two-cavity mold shown. **Parts with metal cores** can be easily produced by this process, so that

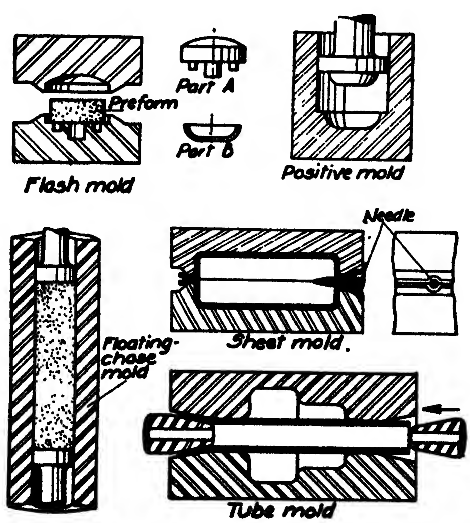


FIG. 18-34. Plastic Molding Methods.

the final product will have the surface characteristics of the plastic with the rigidity of metal. The insert need not be carefully finished for plastic covering, as is the case when a metal die casting is prepared for plating.

247. Compression molding is employed for parts that are too large for successful injection molding, or parts of such thickness that excessive shrinkage must be guarded against. The commonest form of compression mold is the **flash mold** which permits excess material to escape during final closure of the mold. The mold charge is a previously compressed tablet, or *preform,* made from powdered or granulated material, and the slight excess flows out between the flash surfaces of the die during final closure. The resulting fin or thin edge must be removed after the part leaves the die, and usually constitutes the only finishing operation required on a plastic molded part. The location of the parting line of the dies is therefore of importance. Flash molds can only be used with tableted material but are less expensive than other forms of compression molds. The use of preforms also saves handling and loading time and eliminates material waste.

When bulk material must be employed, a **positive mold** is used. The material must be accurately weighed or measured before loading since no excess is permissible in the mold. The dies are more subject to wear than flash mold dies. Positive molds may be equipped with *strippers* for removing deep cup-shaped parts; they are also made with right and left die halves and a central plunger for parts that cannot be conveniently removed from a one-piece die. The **floating-chase mold** is used for parts whose length is great compared to their diameter. This mold consists of two independent plungers in a tubular die. Both plungers act upon the material so that a uniform density in the part may be attained. Floating-chase molds are expensive to construct and maintain and are not used if other processes are applicable.

248. Blowing molds use material in sheet or tube form which is expanded to the finished shape by air, water, or steam pressure. **Tube molds** consist of two die halves, which are loaded with the stock and closed, and the stock is clamped in place by two nozzles. Steam under pressure is admitted through the nozzles and expands the stock to fill the mold. The part is then cooled by circulating water through the nozzles. In **sheet molds,** the sheets are clamped between two die halves, and a hollow needle is inserted through a groove in the dies. The heated dies render the material plastic, and compressed air is admitted through the needle until the material conforms to the mold shape. The needle is then removed and the finished halves of the part are welded by a pressure sufficient to bring the die edges together, which also cuts off the excess stock.

249. Centrifugal casting is a rather specialized phase of foundry practice. Originally used for producing cast iron pipe, it is now employed for casting steel gear blanks that require good physical characteristics and

excellent grain structure, such as ring and transmission gears for trucks, tractors and other automotive vehicles.

Fig. 18-35 illustrates the essential principles of a **centrifugal mold** for a rear-axle ring gear. The mold consists of a steel cope *C* and drag *D*, with a dry sand pouring basin *B*, and a dry sand core *K*. The cope is held on the drag by four weighted levers *W*. The dies are made of low-carbon steel with percentages of chromium and molybdenum. Eighteen of these molds are placed on the periphery of a large horizontal turntable which serves as a continuous conveyor for the loading, casting, cooling and unloading operations. The gears are made of a .35% carbon steel, with small percentages of copper, silicon, manganese, molybdenum, and chromium.

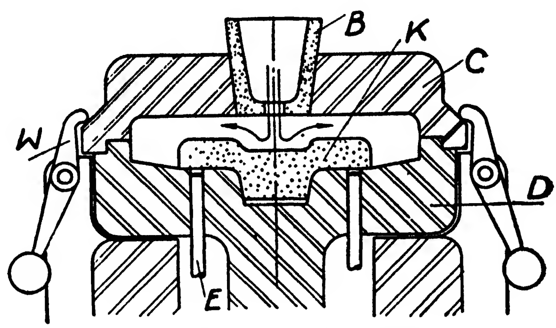


Fig. 18-35. Centrifugal Mold.

The alloy is melted in a 15 ton electric furnace that delivers its charge to a holding furnace at the pouring station of the turntables by ladles suspended from monorail cranes.

As each mold approaches the pouring station, the mold automatically begins to revolve. The speed of rotation varies with the size of the casting; a 7½" gear, for example, is cast at a mold speed of 350 r.p.m. The metal is poured at a temperature of about 2900° F., and the molds pass through a cooling tunnel. After spinning for two minutes, the molds reach the unloading station where the rotation of the mold is automatically stopped to enable the casting to be removed. The mold is elevated and the casting is stripped from the mold by the ejector rods *E*, which are cam-actuated, and a new core *K* is put in position. The cope *C* is replaced and clamped, a new pouring basin is inserted, and the mold is dropped into pouring position.

Each revolution of the turntable takes place in four minutes, resulting in a production rate of 270 castings per hour. The use of steel molds furnishes castings that require only 1/32" to 1/16" machining allowance, and with much less draft than is required for forgings. The surfaces of

the castings are usually smooth so that no snagging operations are required prior to machining.

250. Cast iron pipe has long been produced in large quantities by a centrifugal process. One type of machine has a cylindrical metal mold with a water jacket for cooling around its exterior. Molten iron is delivered from a ladle to a long trough that has a spout at its discharge end. At the beginning of the casting operation the trough extends its full length within the hollow mold which rotates at high speed. The metal is deposited uniformly on the surface of the mold by moving the mold gradually away from the end of the spout as the metal is poured. As soon as the metal in the mold has solidified, the pipe is withdrawn from the mold by a puller attached to the bell end. The casting cycle is repeated after a new head core has been inserted for the bell, and the mold returned to pouring position. Pipe from 3″ to 24″ in diameter and up to 18′ long is cast by this process, and is generally annealed immediately after casting and cooling.

In another process, the iron is cast centrifugally in metal molds lined with molding sand. The sand is rammed around the metal patterns within the cylindrical flasks and is skin-dried after the patterns are withdrawn. Annealing is unnecessary for cast iron pipe that is produced in sand-lined molds by the centrifugal process.

CHAPTER 19

PRODUCTION FORGING AND OTHER PLASTIC PROCESSES

251. Mass production processes that utilize the characteristic of plasticity may be considered under two general heads: hot-working and cold-working. **Hot-working processes** of importance comprise rolling, tube drawing, extruding, and drop and machine forging. However, **cold-working processes** that are closely analogous to some of these processes will also be considered in this chapter.

252. For large-scale production, **rolling** is one of the simplest and cheapest methods of fabricating members of uniform section such as bars, plates and other structural members. A **rolling mill,** shown in Fig. 19-1, consists of two or more rolls made of cast iron or heat-treated steel, with horizontal axes in a vertical plane. The stock or **billet** to be rolled is pushed between the rolls and is carried forward by the friction between the rolls and the work. Since the center distance between the roll axes is fixed, the thickness of the billet is reduced with a corresponding increase in length and a slight increase in width.

Fig. 19-2 illustrates several types of rolling mills. The illustration at *A* represents a section of a train of **two-high non-reversing rolls.** *T* represents the direction of travel of the billet, *R* the rolls, and *P* the power-actuated or live rollers for bringing the billet to the rolls, and for carrying it away from them. After a pass through these rolls, the billet must be returned to the original side of the rolls for further passes, and it is therefore lifted with tongs to the top of the upper roll where the friction between the billet and the upper roll carries it back as shown by the arrow *U*. The illustrations at *B* and *C* show the operation of a train of **two-high reversing rolls** in which the billet is sent through one set of grooves in the rolls for the first pass. The rolls *R* and the live rollers *P* are then reversed in direction, as illustrated at *C*, to bring the work back through another set of grooves. This type of mill requires a reversing motor or engine as a prime mover, but acts on the material at every pass of the billet.

Fig. 19-2 *D* shows a **three-high rolling mill** in which the middle roll rotates in a direction opposite to those of the upper and lower rolls. The billet passes between the upper and middle rolls on the first pass as indicated by *T*, and between the middle and lower rolls on the second pass. This arrangement eliminates the time-consuming idle pass of the two-high

non-reversing mill, and the expensive motor or engine reversing equipment required in the two-high reversing mill. The billet must be lifted to the

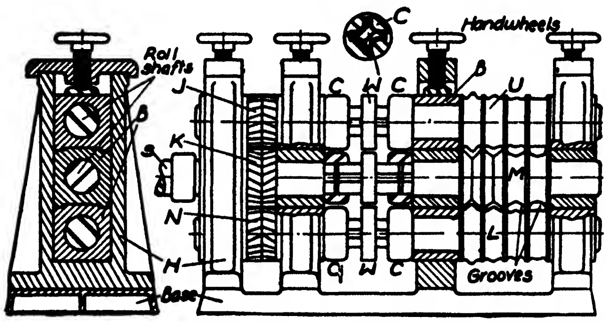


FIG. 19-1. Three-high Multiple-pass Single Stand Rolling Mill.

upper set of grooves at every other pass, however. Billets of comparatively small section are lifted with hand tongs, but larger work is sometimes handled by an auxiliary set of live rollers Q which swing into position for lifting and starting the billet.

253. Fig. 19-1 shows the details of a **single multiple-pass stand** of a three-high rolling mill for rolling a structural angle from a billet of rectangular section. The mill is driven by the motor drive shaft S at the left. The middle herringbone pinion K drives the upper and lower pinions J and N. These pinions are integral with their shafts which rotate in bearings B in the housings H. The

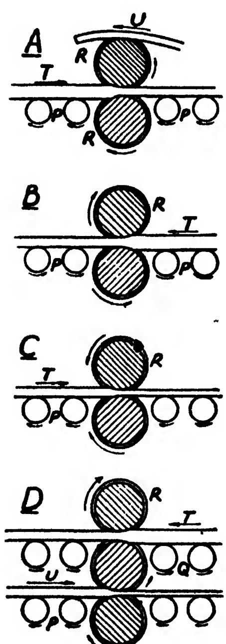


FIG. 19-2. Rolling Mill Types.

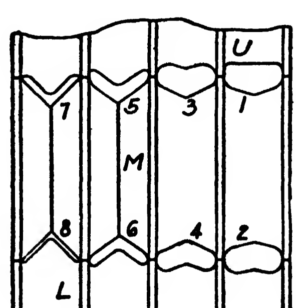


FIG. 19-3. Grooves for Rolling a Structural Angle.

pinion shafts drive the three rolls U, M, and L by two couplings C and a wabbler W, which serves as a flexible coupling and permits some misalign-

ment of the roll axes. The wabbler is designed to fail if great resistance to rotation is encountered, which may happen if a bar sticks between the rolls. The expense of replacing the wabbler is very low as compared with that of the more costly rolls or gears.

Fig. 19-3 shows an enlarged detail view of the **roll grooves** shown in Fig. 19-1. The "odd-numbered" grooves indicate forward passes and

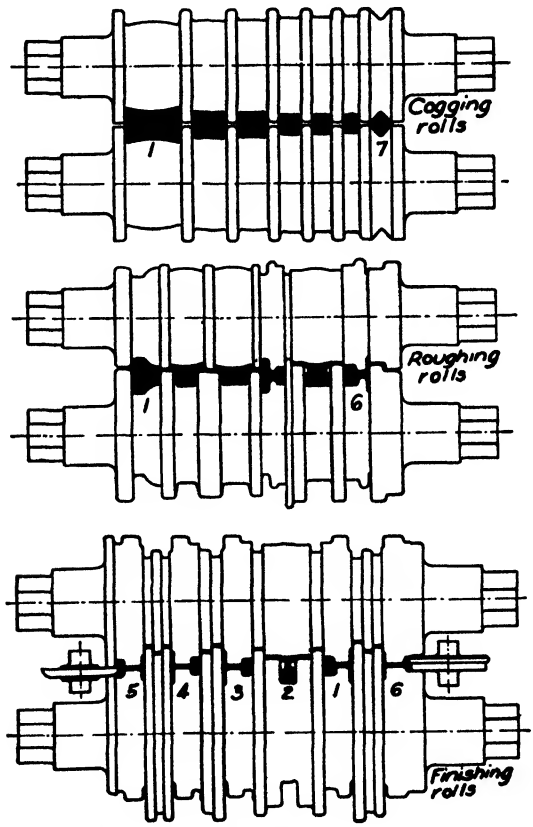


FIG. 19-4. Roll and Groove Sequence for Rolling a Trolley Rail.

the "even-numbered" grooves return passes. Fig. 19-4 shows a set of three rolls for a **trolley rail section.** The billet is reduced in size in seven passes in the *cogging* rolls, roughed to shape in six passes in the *roughing* rolls, and finished in six passes in the *finishing* rolls. The head of the rail is formed solid in passes 1 to 4 in the finishing rolls, and an auxiliary roll with a vertical axis is employed at the fifth pass to rough out the groove in the rail. A second auxiliary roll is used in conjunction with the main rolls

in the sixth pass to finish the groove while the section of the rail is brought to final size.

254. Rolling mill practice uses heated billets at a temperature of 2000° F. or higher, but many shapes, particularly circular, rectangular and other sections, and sheets and foil, are finish-rolled in a cold state. The bar is rolled to approximate size in the hot state and is cooled and pickled to remove the scale. It is then rolled in a finishing mill to a size variation of .002″ or less for round, square or hexagonal bars. **Cold rolled steel**

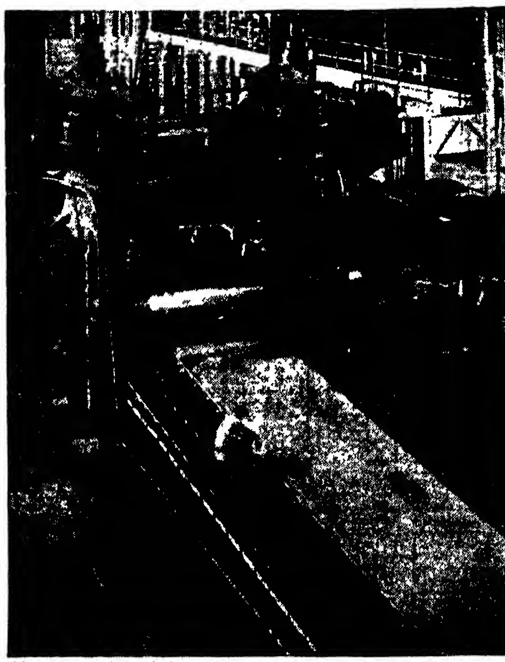


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FIG. 19-5. Plate Mill.

is extensively used for shafting and as stock for screw machine and other operations; in the *as-rolled* state it has a surface *skin* that is more wear-resistant than the basic material.

Fig. 19-5 shows a **plate mill** for rolling aluminum plates and sheets. The material is cold-finished, and the rolls must have a mirror-like surface in order to produce the excellent finish shown on the product.

Modern hot-rolling practice generally utilizes the **continuous mill,** which consists of a series of two-high non-reversing single pass stands, with live roller beds between them so that the work passes through each stand consecutively. The roll speed at the successive stands is carefully adjusted to the work, since the rolled piece is frequently so long that it will be pass-

ing through several stands at the same time. For strip and small bar rolling, several roll stands are placed side by side and the work is shifted from one stand to the next by curved guides or *repeaters*.

255. Seamless tubing is produced by either of two manufacturing processes, piercing and cupping. In the **piercing process** a square bloom from the heating furnace is rolled into round bars and cut to different weights, depending upon the size of the tube required. The bars are allowed to cool, are centered and inspected, and are set to the piercing mill. The round billet is heated almost white-hot, and is pushed into the **piercing mill** until it is caught by revolving rolls which force it over the point of a mandrel as illustrated in Fig. 19-6. The metal is displaced from the center of the hot billet to the exterior. The pierced billet is rough and not particularly true to size, and is short because of its wall thickness. To change this thickness to length, it is rolled through adjustable rolls over a mandrel held in the roll groove by a long bar as illustrated in Fig. 19-7. The tube is next

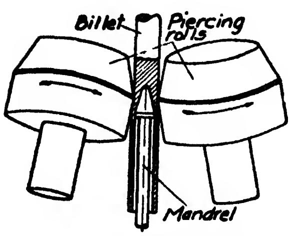

FIG. 19-6. Piercing Mill.

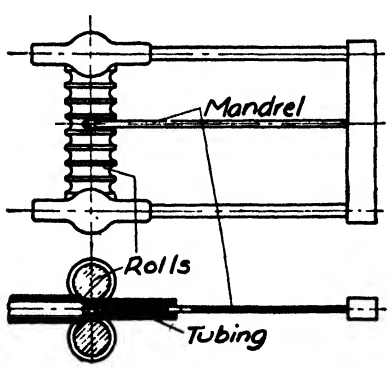

FIG. 19-7. Second-operation Rolls for Seamless Tubing Manufacture.

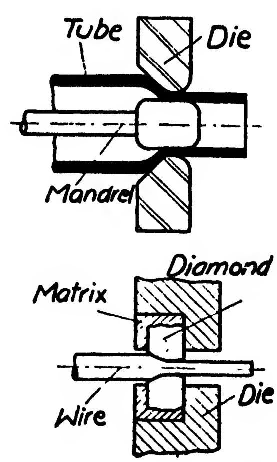

FIG. 19-8. Tube and Wire Drawing Dies.

subjected to a *reeling* operation in which it is passed between skew rolls and over a mandrel, which removes the mill scale and produces a smooth burnished surface.

256. Cold-drawn tubes are given the same piercing, reeling and sizing operations as hot-finished tubes. The tubes are pointed at one end

and pickled to remove any scale. The pointed end of the tube is then inserted in a hole in a die as shown in Fig. 19-8, and a mandrel is placed in the position shown. The end of the tube is grasped by tongs which have a hook that catches on a traveling chain on the draw bench. The tube is drawn or squeezed between the die and the mandrel which is held in position by a bar as illustrated. Seamless tubes may be drawn through dies of varying diameters from two to twenty times to obtain the required diameters. After the final drawing operation, the tubes are annealed and straightened. Fig. 19-9 shows a **draw-bench** with two sets of dies, traveling **heads,** and chains.

257. Fig. 19-8 also illustrates **cold-drawing of wire** which is effected by a draw bench similar to that used for tubing. **Wire drawing dies** are generally made of tungsten-carbide or diamond inserts held in a die by a soft metal matrix. The wire is generally coiled upon a reel whose rotation pulls the wire through the die. The drawing operation increases the unit tensile strength of the wire; for instance, a ½″ carbon steel wire has an allowable design stress of 70,000 psi, but ⅓″ wire may be stressed to 90,000 psi.

258. The manufacture of the **diamond dies** is a rather interesting process. A stone of the necessary size is selected and two parallel surfaces are cut on it by abrasion with another diamond; a countersunk hole is then drilled in each side by using a rotating conical steel point coated with diamond dust. After this operation, a hole is drilled through the diamond, using a cylindrical steel rod of the proper size and applying diamond dust to its flat end. The hole is drilled halfway through from one side, and the operation is completed by turning the diamond over and drilling from the other side. The hole is then *bell-mouthed* by using a diamond chip as a cutting tool, and the die is completed by carefully polishing the hole.

259. The Stiefel mill illustrated in Fig. 19-10 is used for expanding tubes of large diameter. The two conical rolls rotate very rapidly, while the tube to be expanded and the mandrel revolve together at the same speed.

260. Large tubes are generally made by the **cupping process,** from circular discs of low-carbon steel instead of round billets. After heating, the disc is cupped by being forced through a cylindrical die by a cylindrical punch. The process is generally carried out in an hydraulic press and is similar in principle to the operation illustrated in Fig. 20-19. After one or more cupping operations, the cup is reheated and passed through a series of dies in a **hot-draw bench,** as illustrated in Fig. 19-11, which has an hydraulically-operated plunger that can travel the full length of the bench. Punches of various sizes can be held on the end of the plunger, and dies of successively decreasing diameter are dropped into recesses in the bench frame, so that the heated elongated steel cup may be forced through

them in succession by the punch. If the tube is to be used for making seamless containers for fluids, the head is left on the bottom of the tube; if seamless tubing is required, the head is cut off in a subsequent operation.

261. Extrusion forging is a process whereby either hot or cold metal is caused to flow by the application of pressure. In its simplest form, a cylinder filled with heated metal is subjected to the action of a plunger which forces the metal through a die opening at the bottom of the cylinder. This process is illustrated in Fig. 19-12 which shows a die for making seamless lead pipe. The fixed mandrel is held in position by four bridges, and

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FIG. 19-9. Drawing Seamless Tubing.

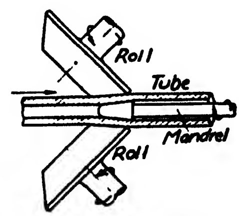

FIG. 19-10. Stiefel Mill.

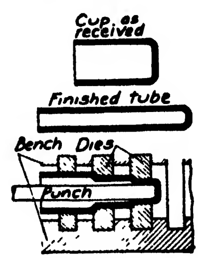

FIG. 19-11. Hot Draw Bench Operations.

the plastic material flows past these bridges and reunites in the die throat.

Fig. 19-13 shows some representative **extruded sections** that can be easily produced in aluminum alloys and other non-ferrous metals. The three shapes shown are practically impossible to produce, as bars of considerable length, by any other forging process.

Fig. 19-14 shows the sequence of operations in the manufacture of **hot-extruded steel cylinders** with a closed end of definite thickness. The essential equipment consists of a cylindrical die *D*, a cylindrical punch *P*, and a supporting ram *R* which closes the throat of the die during the preliminary stages of the process. The steel billet or blank *B* is heated to approximately 1800° F. and placed in the die as illustrated at stage 1. As the punch descends, the billet is pressed down into the throat of the die,

as at stage 2, until it is forced against the supporting ram *R*. The punch continues descending until the metal occupies the entire space between *P, R,* and *D,* fixing the thickness of the end as shown in the third stage. The ram then recedes rapidly and the continued downward motion of the punch ex-

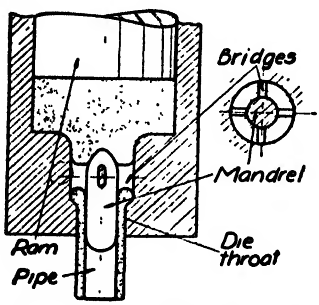

FIG. 19-12. Manufacture of Extruded Lead Pipe.

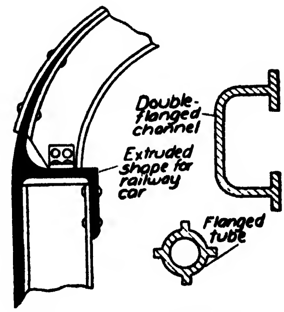

FIG. 19-13. Representative Extruded Shapes.

trudes the metal through the die. The downward motion continues until the condition shown at stage 5 is attained, when the punch is removed. The ram lifts the finished part back through the die until it projects far enough above it so that the flange formed on the upper end may be seized by a pair of tongs.

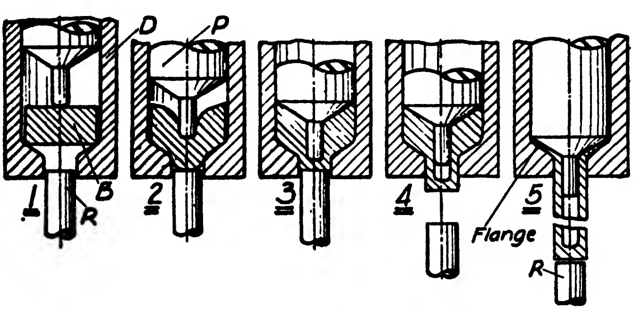

FIG. 19-14. Sequence of Operations in Hot-extruding Steel Cylinders with Closed Ends.

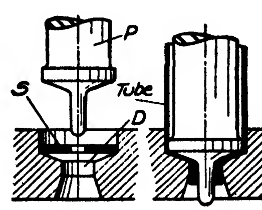

FIG. 19-15. Cold-extruding Collapsible Tubes.

In stages 4 and 5, it may be noted that the punch continues its stroke to extrude the material after the ram has been removed. The hollow extruded section travels through the die throat at a rate which is from *four to six times* as great as that at which the punch descends. The base of the forging therefore travels ahead of the punch, and is not subjected to drawing strains while the walls of the part are being formed. This is in contrast to the

cupping method of drawing illustrated in Fig. 19-11, in which the base of the tube is subjected to heavy strains.

Automobile engine valves are extruded by a similar arrangement; since the valve stem is solid, the punch *P* has a flat end and no supporting ram is employed.

262. Fig. 19-15 shows the sequence of operations in **cold-extruding collapsible tubes** from aluminum alloy or lead-base materials. The punch has a shoulder whose diameter equals the required inner diameter

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FIG. 19-16. Board Drop Hammer.

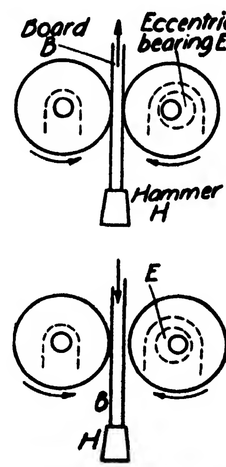


FIG. 19-17. Principles of Operation of the Board Drop.

of the tube. The recess in the die *D* has a diameter equal to the outer diameter of the tube. A punch slug *S* is placed in the die, and the punch descends causing the metal to flow up around it. The thickness of the tube is controlled by the clearance between the punch and the die. The surfaces which control the direction of the flow of metal must be carefully polished in the direction of flow. In some instances the cylindrical portion of the die throat is threaded so that the threads will be formed in the neck of the collapsible tube.

263. **Drop forging** is the process of shaping hot metal by forcing it into die cavities by the application of sudden blows. There are two principal forms of drop hammers—the steam hammer and the board drop—that are used for drop forging operations. The operation of the steam

hammer has been described in Chapter 6; the **board drop** is illustrated in Fig. 19-16 and 19-17, which show the principle of operation. The hammer or ram H is fastened to maple boards whose upper ends pass between two rotating rolls. When the rolls are moved towards each other, they lift the board as illustrated in Fig. 19-17. At the top of the stroke the rolls automatically separate and release the board, permitting the ram to drop and strike the blow. Most board drop hammers are equipped with a device for changing the length of fall and consequently the force of the blow. In Fig. 19-16, B is the board, R one of the elevating rolls, and A the ram, which is guided between the columns of the frame F. The upper die half is fastened to the ram by means of the dovetail shown, and the lower die half to the sow-block S, which is a heat treated block that is designed to resist the hammer blows.

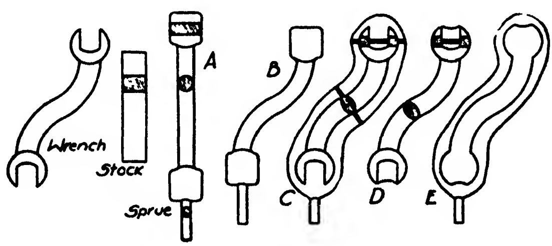


FIG. 19-18. Sequence of Operations in Drop-forging an S-Wrench.

Forging presses, in which the vertical ram is actuated by a pitman operated by an eccentric, are used for impact extrusion, hot forging, and hot and cold coining operations. These presses are available in capacities up to 2000 tons.

264. Fig. 19-18 illustrates the sequence of operations in making a **drop-forged S-wrench.** The dies for this wrench are shown in Fig. 19-19, and consist of a central finishing cavity G, a bending die K at the left, and flatters H and fullers J at the right, for the preliminary *breakdown* operations. As the forging blank must be larger than the completed forging in order to insure sound forgings of correct shape, a recess F, known as the *flash,* is cut around the cavity G to permit the excess material to squeeze out at the sides of the die cavity.

The wrench is made from stock of rectangular section and the result of the first breakdown operation is illustrated at A, Fig. 19-18. The stock is first held in rectangular-bar tongs until the sprue has been formed between the fullers J; the stock is then held by the sprue while the central portion is fullered, and the ends are flattened between H. The stock is then placed between the bending dies K as shown in Fig. 19-19, and bent to approximate form. The bent forging is then placed in the die cavity G and forged with

a single blow. The appearance of the forging after this operation is illustrated at *C*, which shows the flash attached to the forging proper. The work is then taken to a trimming press and the flash is cut from the forging at one stroke. *D* represents the completed drop forging and *E* the scrap flash.

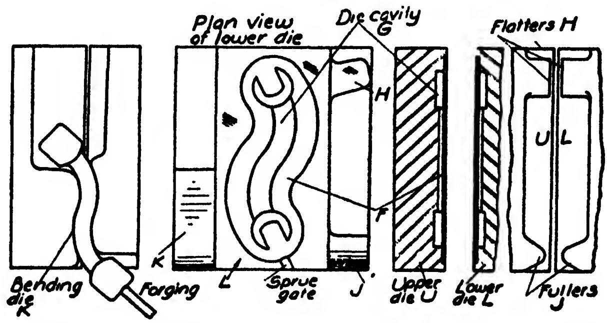


FIG. 19-19. Drop-forging Dies for S-Wrench.

(The flash is also referred to as the fin.) The flash between the wrench jaws is not trimmed out, since it keeps the sides of the jaws in alignment while the forging is cleaned, and it can easily be removed when the inner surfaces of the jaws are machined.

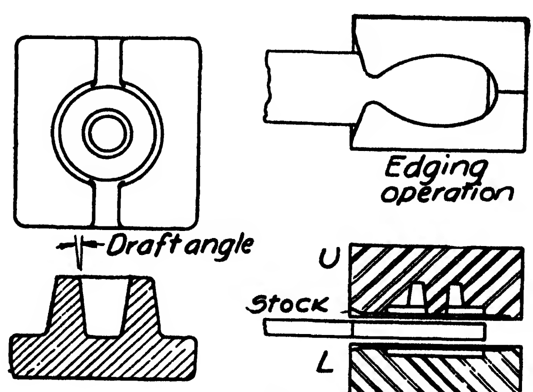


FIG. 19-20. Small Drop Forging.

The trimming die is similar in principle to the punches and dies for round holes described in Chapter 6; the punch has an outline corresponding to the profile of the forging at *D*, and the die has a hole that fits the punch closely.

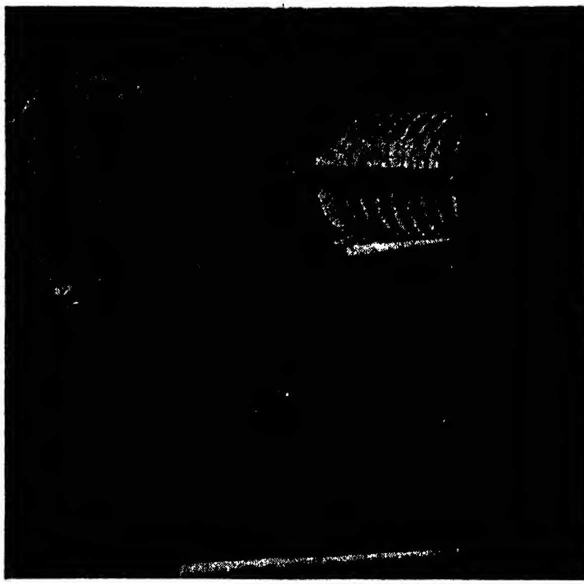
265. Fig. 19-20 illustrates a small drop forging which has a comparatively deep hole; the forging is made of rectangular stock, and the only

preliminary break-down operation is performed by an **edger at the side of the die.** The edger *necks* the stock, and *gathers* the portion between the die halves to upset the end so that sufficient material will be available when the stock is placed in the finishing die. The importance of **forging draft** is illustrated; the draft angle should not be less than 7° for a primary drop forging operation, although practically vertical surfaces can be produced by subsequent trimming and finishing dies.

The Erie Foundry Co.

Fig. 19-21. Drop-forging an Aircraft Propeller Blade.

266. Forging rolls are used for the **break-down operations** preliminary to drop forging, and for reducing short thick sections to long slender sections. Their action is similar to that of rolling mills, but the forging rolls make use of only a portion of a revolution to reduce the stock; the remainder of the roll has a blank clearance space for the ends of the stock that are to be left full size. The operator stands at the back or emerging side of the rolls, and when the clearance space appears, he places the work into this space. When the reducing portion of the rolls comes in contact with



Ajax Mfg. Co.

Fig. 19-22. Forging Rolls.

Acme Machinery Co.

Fig. 19-23. Forging Machine—Dies Open.

Acme Machinery Co.

Fig. 19-24. Forging Machine—Dies Closed.

the work, it reduces the stock and ejects it from the rolls towards the operator. At the next open portion of a revolution of the rolls, the stock is again inserted for a second reducing operation. By this method only as much of the length of stock is reduced in area as is required. Forging rolls contain a number of grooves, depending upon the number of passes

National Machinery Co.

FIG. 19-25. Forging Hexagonal Nuts.

required. Forging rolls are also extensively used for rear axle shaft forgings, long bolts and spring leaves.

267. **Machine forging,** as distinguished from drop forging, is an upsetting or heading process applied to forgings made from bar stock. A **forging machine** consists essentially of three dies: a movable die *M*

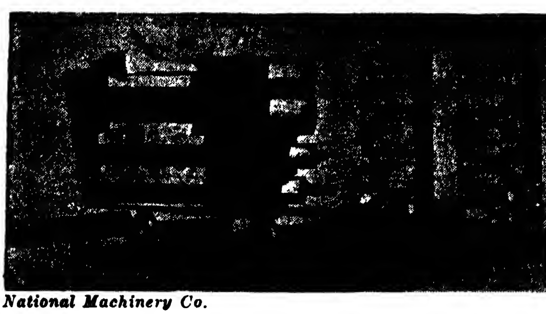

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FIG. 19-26. Forging a Differential Side Gear.

is opposed to a stationary die *S*, and the two are used for gripping the bar stock; a third or header die *H* moves in a plane parallel to the parting surface between the clamping dies, and handles the major portion of the work of forging. The relation of these dies is illustrated in Fig. 19-23 and 19-24; the operator inserts the heated bar stock in each die cavity in turn. (The operator stands so that he views the dies in the same position as the

reader.) The die operation is automatic and is controlled by a treadle-operated clutch. The operator inserts the bar, steps on the treadle (and releases it again) and the die M closes, gripping the bar. The header die H moves forward to perform its operation and returns to starting position, and the die M opens, completing the cycle. The operator then moves the bar to the next die cavity and again steps on the treadle to begin the next cycle.

268. Fig. 19-25 shows the dies for **forging a hexagonal nut** for a steam turbine from a bar 2¾" in diameter. The stock is gathered and upset in a single blow in the first (top) impression, resulting in a forging A. In the second (middle) impression the header tool enters and shapes the nut

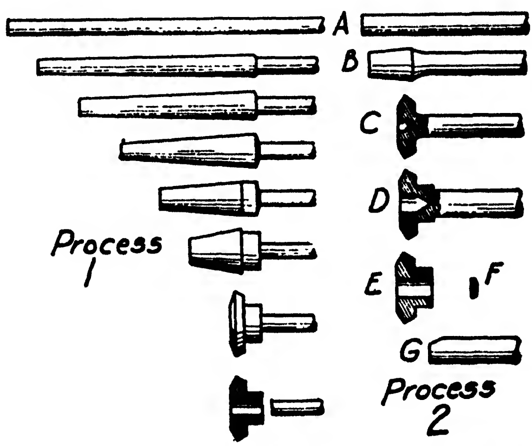

FIG. 19-27. Comparison of Machine Forging Methods.

by combined piercing and expanding. The last operation, in the third die impression, serves merely to punch the bar out of the nut without waste, since the wad of metal from the second impression remains on the bar and is used for the succeeding part.

269. Fig. 19-26 shows how a **differential side gear** blank for an automobile rear axle may be forged in four passes and one heat. In the first and second operations the head of the bar is upset, flattened and indented, as illustrated at B and C. In the third operation, the result of which is seen at D, the piercer penetrates to almost the full depth of the gear and displaces the stock for the gear hub into the die impressions. In the fourth operation the forging E is sheared from the bar G, and the small amount of metal remaining in the hole is removed by the punch on the lowest heading die in the form of a slug F.

This series of operations is also illustrated in Fig. 19-27, process 2, in which A represents the bar stock and the other letters correspond to those

of Fig. 19-26. By contrasting this process with that of Fig. 19-25, it may be noted that in one instance the size of the bar is equal to the size of the

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FIG. 19-28. Forging a Crankshaft.

hole in the nut, while in the other, the bar size is appreciably greater than the hole diameter. Process 1, Fig. 19-27 illustrates an older method of producing the gear forging by using a bar size equal to the hole diameter.

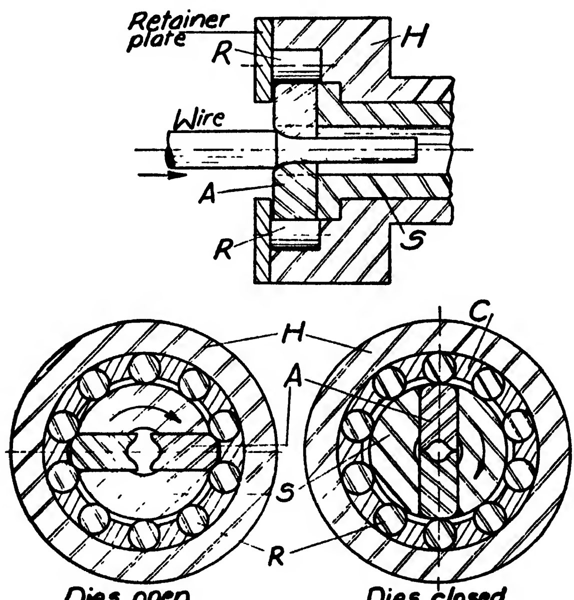

FIG. 19-29. Rotary Swaging Machine Principles.

While this method completely eliminates waste material, it requires seven operations and two heats to forge the gear, because only a *limited* portion of the unsupported bar length can be upset in any *one* operation.

270. Fig. 19-28 shows a set of dies for a rather unusual machine forging operation. The **crankshaft** at *B* is usually made by **drop forging**; in this process the stock is first bent in a break-down die, then placed in a die cavity and forged; and the flash is cut off in a trimming press. In **machine forging** this part, the first operation is bending the bar stock, which is accomplished in one stroke in the bending die at the top. The result of this operation is shown at *A*. On the same heat, the bar is placed in the die which consists of a stationary rear section and sliding middle and front sections in both die halves. The end of the header strikes the front sliding section which moves back until it touches the middle section, and both sliding sections are then forced by the header against the stationary rear section of the die halves. This movement gathers sufficient material to form the crankshaft cheeks, and results in a completed forging as shown at *B*.

271. Multi-diameter bars may be produced by **rotary cold-swaging** which is illustrated in principle in Fig. 19-29. **A rotary swaging machine** consists of a spindle *S* that carries two hammers or dies *A*, which are free to slide in the spindle head. The spindle head is surrounded by ten cylindrical rolls *R*, spaced by a cage *C* and supported by an annular housing *H*. The stock is fed through the hole in the spindle, and is acted upon by the die surfaces of the hammers, which close on the work as the rotation of the spindle causes the other ends of the hammers to pass between successive pairs of opposed rolls. With ten rolls, there are ten blows for every rotation of the spindle. Rotary swaging can be employed for straight or tapered reductions in solid stock of any regular section, such as round, square, or hexagonal. It can also be used for pointing circular tubing, for straight reduction in tubing if a mandrel is employed to hold the inner diameter to size, and for attaching cylindrical ferrules to cable ends.

CHAPTER 20

PRESSWORK AND ALLIED PROCESSES

272. Cold-working metal processes may be divided into four general groups: cutting, bending, drawing, and squeezing. Cutting processes as applied to sheet metal are further subdivided into shearing and blanking processes; the term **shearing** as used here implies straight cuts on plates and sheets, and the operation is performed on presses similar to those in Chapters 6 and 7. **Blanking** is the process of cutting parts of almost any shape from sheet metal with a punch and die in a power-actuated press.

273. One of the most common machines for **blanking** and other sheet metal press operations is the **open back inclinable press** illustrated in Fig. 20-1. The ram moves vertically in guides on the frame, and is actuated by a pitman or short connecting rod which is driven by an eccentric on the eccentric shaft. In presses with comparatively long strokes, the pitman may be driven by a crank on the shaft. The eccentric shaft is driven by a flywheel pulley; the flywheel is used to store up energy for the greater part of the revolution of the shaft and to deliver it to the ram during the comparatively short cutting period. The flywheel is coupled to the shaft for one revolution at a time by a jaw clutch and a single-revolution actuating mechanism similar *in principle* to the arrangement shown in Fig. 6-20. An automatic brake mechanism at the end of the shaft opposite the flywheel stops the rotation of the shaft at the highest point of the stroke. The clutch mechanism is actuated by a foot treadle. The lower die is attached to the bolster plate, the upper die or punch to the lower end of the ram. The frame of this press may be inclined by swivelling it about a fulcrum bolt *C* and clamping it in position with bolt *B*. The press frame is often inclined for operational convenience and to permit the blanks to drop or slide clear of the die.

Double-crank presses have two pitmans for moving the ram, and are used for sheet metal operations on pieces of considerable area, or of long length and narrow width. They are also used for perforating rows of holes, for straight-line bending operations, and for operating groups of progressive dies. The principle of operation is essentially similar to the inclinable press but the ram is actuated by two pitmans driven by a two-throw crank shaft. The ram slides in guides between two vertical uprights

holes in sheet metal or in previously blanked parts. Fig. 20-4 shows the front-sectional and right side views of a progressive blanking and piercing die for a plain washer. The stock is fed from right to left between the stock guides on the die, by an automatic feeding device as indicated by the arrow. The hole in the washer is punched first, and the strip is then fed the proper distance so that the washer may be blanked; the punch *P* pierces a hole for the next washer at the same time. Although an automatic, carefully-set feed is used, the conical pilot on the blanking die *B* insures the production of washers whose outer periphery is concentric with the hole. The stripper plate *S* prevents the stock from coming up as the punches *B* and *P* are lifted on the up stroke of the ram. The illustration also shows the appearance of the stock at the conclusion of one feed cycle.

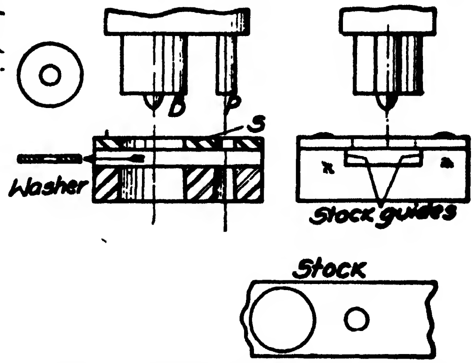

FIG. 20-4. Progressive Blanking and Piercing Die for Plain Washer.

Fig. 20-5 shows a **combination** blanking and piercing die for producing the same washer. The blanking die *B* can slide in the holder *H*, and the holder and the piercing punch *P* are fastened to the upper die body *U* which is attached to the press ram *R*. The plate *V* serves as a support for the stock, and strips it from the lower die *D* after the washer has been blanked and pierced. The lower die body *L* is attached to the bolster plate of the press. Springs *T* and *S* serve to return the blanking die *B* and the plate *V* to position after the operation is complete. The blanking die *B* *leads* the piercing punch *P* slightly, so that the stock is clamped by the cutting action of *B* before *P* begins to cut. If *P* were set to contact the work first, the blanking die might twist or tilt the stock as it began to cut, and the comparatively slender punch might be broken. The use of a combination die for producing the washer insures concentricity without depending upon

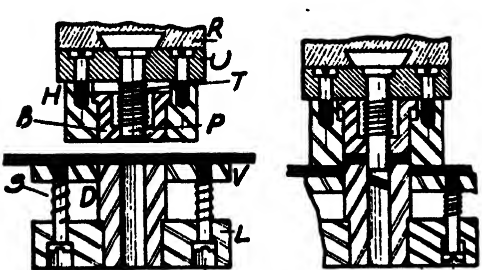

FIG. 20-5. Combination Blanking and Piercing Die.

the press feed, although an accurate automatic feed is used to eliminate waste in the stock.

275. To insure accurate work and to eliminate the possibility of chipping the edges of the punches and dies, the two members must be very carefully aligned when they are placed in position on the press ram and bolster. This operation must be performed every time a different die is used, and requires the services of an expert die-setter. To eliminate the care that is necessary in die setting and the undesirable effects of too much freedom in the ram slide, many punches and dies are mounted in a **sub-press or die set**, Fig. 20-6. The die set consists of a punch plate *L* to which the punch or the upper half of the die is fastened, and a die base *Q* to which the lower half of the die is fastened. *L* and *Q* are held in alignment by two guide pins *J*, which are press fits in *Q* and slide in bushings *K* in *L*. To serve the purpose of maintaining proper relative location of the punch and the die, it is desirable that the sliding clearance between the bushings *K* and the pins *J* should be smaller than the clearance between the punch and the die. The die base has slotted lugs *U* for holding it to the bolster of the press, and the punch plate is equipped with an integral shank *M* to fit the ram.

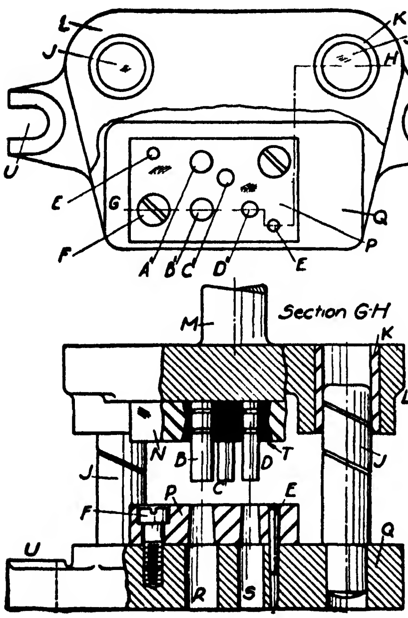

Fig. 20-6. Sub-press Die.

Standardized die sets consisting of a punch plate and a die base with either two or four guide pins are commercially available. The dies shown in Fig. 20-6 consist of a die *P* and a punch holder *N*, in which four punches *A*, *B*, *C*, and *D* are set. Both *P* and *N* are fastened to *Q* and *L* by two screws *F*, and are located by two dowels *E*. The punches are held in *N* by Cerromatrix, a patented alloy, which has a comparatively low melting temperature (about 248° F.) and expands upon solidification at the rate of approximately .002" per inch. (This expansion is the net result of solidification, cooling and aging effects, and is principally due to the presence of bismuth in the alloy.) A comparatively rough hole, sufficiently large to permit the alloy to flow completely around all the punches, is cut in the

punch holder blank. The punches are located in N by aligning them with the die holes in P and the alloy is poured around the punches. The assembly is allowed to stand for twelve hours or more before using. The punch shanks have annular grooves to bond them in the matrix. The melting point of the alloy is sufficiently low so that there is no danger of drawing the temper or affecting the hardness of the punches. The process is particularly applicable where closely-spaced punches of irregular section are used.

Cerromatrix is used for making forming dies for comparatively short runs, by locating a hand-formed sheet metal template vertically in a box of suitable size, and pouring the alloy on each side of the template simultaneously. This is a rapid method of making a pair of dies in which the

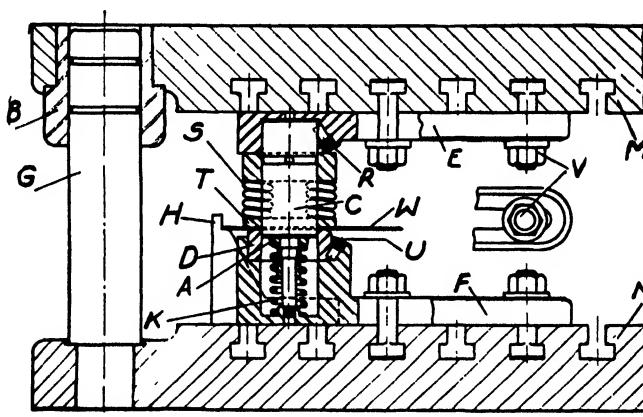

FIG. 20-7. Universal Perforating Die Set.

necessary clearance is obtained automatically. Cerromatrix is also used for locating drill bushings in drill jigs, for making small chucks for holding irregular work, and for making master molds for engraving machines and duplicators.

276. Fig. 20-7 illustrates a **universal perforating die** or general-purpose die set which is adaptable to a wide variety of work. The unit consists of a die set or sub-press with a punch plate M, a die base N, and guide pins G and bushings B. The die D is held by set screw U in a die holder F, which is clamped to N by two tee-bolts. The punch C is similarly held in a punch holder E. The stock W is stripped from the punch after perforation by stripper ring T actuated by four springs S, and the blank is forced upward, out of the die by a sleeve A actuated by spring K. The stock is located by an adjustable gage H which is held to the die base by two tee-bolts.

These die sets are used for short run work, or for piercing and perforating operations where the cost of a single-purpose die is prohibitive.

Twelve or more punch and die holders of different sizes may be used with one die set, and may, since the parts are standardized, be used for an entirely different arrangement of holes on the succeeding job. As many gages H as are required may be employed to properly locate the stock for duplicate production.

277. Fig. 20-8 illustrates a semi-universal process for **blanking** and **forming** operations on comparatively soft metal sheets in an hydraulic press. A live rubber pad P is held in an open end frame F, which is of such size that it telescopes snugly around the edges of the press bed V. A gang plate G for mounting the forming or cutting dies is placed on the press bed, the dies B are nested on the gang plate and dowelled in place, and the sheet W to be blanked is placed over the dies. (The dimensions of the sheet are of course less than the inner dimensions of the frame F.) The press ram is then brought down and the rubber pad serves as the upper half of the die to perform the blanking operation. Q indicates the blanked parts and S the scrap stock. The lower illustration in Fig. 20-8 shows the same pad P used for forming part W; in this case a master form M is bolted or dowelled to the press bed V.

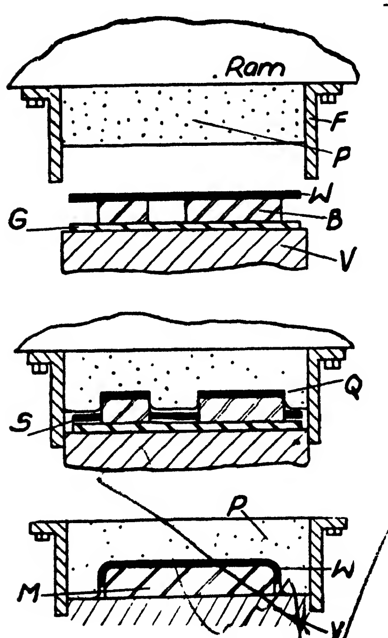

FIG. 20-8. Forming and Blanking by Using a Rubber Pad.

The process is applicable to short run work on non-ferrous materials 1/16″ or less in thickness, and for large and small parts of almost any outline. The blanking dies may be made of case-hardened common steel while the forming dies are usually made of Dowmetal, aluminum alloys, or similar materials by casting in sand molds made with simple wooden patterns, and finishing the dies by filing. In one instance, blanking dies are made of a 1/16″ thick chrome-molybdenum steel plate fastened to a pressed-fiber block ⅜″ thick by wood screws; the block is in turn dowelled to the gang plate.

Another method of handling short run work by cutting out the blanks, either singly or in multiple on a metal-cutting band saw, has been described in Chapter 16.

278. Fig. 20-9 *D* shows a portion of an armature lamination for an electric motor. This lamination may be produced by two methods: by making a complete blanking die so that one lamination is produced at every stroke of the press; or by first blanking a circular disc, piercing the shaft hole and keyway, and then using a single-slot punch and die in combination with an indexing press feed for punching one slot at a time and indexing automatically to the next slot. The first method is usually employed for large-scale production and comparatively small parts where the higher die cost can be absorbed in a reasonable period of time. The second method requires far more production time, but a single-slot punch and die can be used for laminations of different diameter if necessary. Another method employed by motor manufacturers is to use built-up armatures composed of

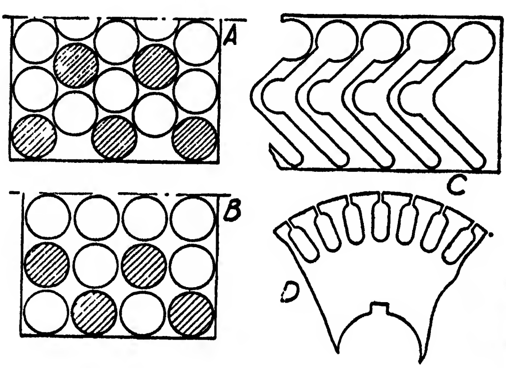

Fig. 20-9. Blanking Layouts.

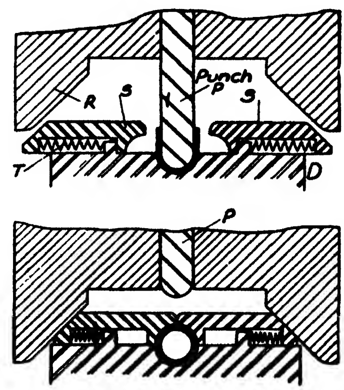

Fig. 20-10. Bending Die for Producing Short Cylinders.

60° or 90° sectors instead of complete circles, and then to make a complete blanking die for a sector. This method affords a comparatively high production rate, although the assembling costs are somewhat higher than for complete-circle laminations.

Fig. 20-9 *C* shows a **strip layout** for a bell crank blank, which is arranged so as to eliminate waste as much as possible. *A* and *B* in the same figure show two methods of strip layout for circular blanks. In each instance multiple blanking die sets are used; the **chain layout** at *B* requires four die sets, as indicated by the cross-hatched areas, while the **staggered layout** at *A* requires five. The blanks cut at one stroke of the press are spaced as shown in order to give sufficient supporting area between the holes in the lower die. While the layout at *A* requires an additional die set, the production rate is about 15% higher, and the stock wastage about 10% less than in layout *B*.

279. Bending dies are extensively used for small and large parts. For parts of uniform thickness, the punch and die are usually similar in profile, and resemble the breakdown bending dies used in drop forging. Fig. 20-10 shows a bending die for forming short cylinders from strip stock in a double action press. The die base *D* has two horizontal slides *S* on it, which are actuated by the cam *R* attached to one of the press slides; the slides *S* are returned to position by the springs. The punch *P* is actuated by the other press slide and does the preliminary bending as illus-

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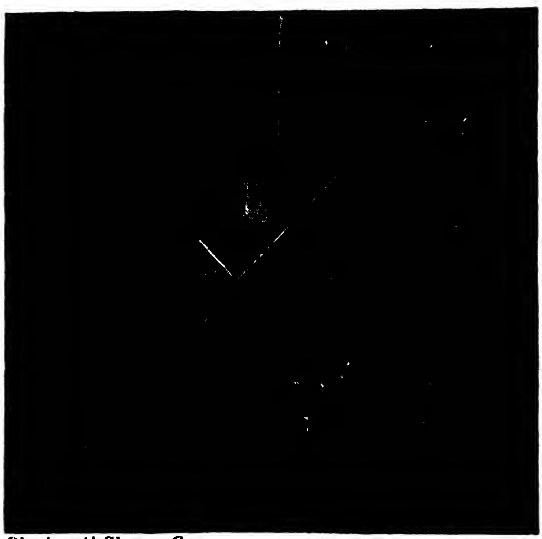
FIG. 20-11. All-steel Press Brake.

trated. This method of production is even faster than cutting off lengths of tubing on a screw machine or milling machine, although the parts are not as accurate. Neither the inner nor the outer diameter of this particular part required any great accuracy, however, as it was used as a spacer sleeve in a small mechanism.

280. Press brakes are extensively used for bending and folding operations on steel plate and metal sheets. A modern press brake is illustrated in Fig. 20-12 and has a ram which is reciprocated by two pitmans and cranks. The ram and the driving mechanism are carried by two vertical housings which are flame cut from solid steel plate. The lower die is carried

by the bed which is bolted to and supported by the housings. The machine is equipped with a single stroke clutch for hand lever or foot treadle operation.

Fig. 20-12 shows a press brake equipped with a **four-way die,** which is used for single bends in different gages of material and is also used for varying degrees of sharpness of bend. Fig. 20-13 shows a **goose-neck die** for forming door tracks, partition posts, and similar channel bends. Four strokes are required to properly shape the part; the folds at the edges are made first. Fig. 20-14 illustrates the application of **progressive dies** on a single brake. Four operations are performed

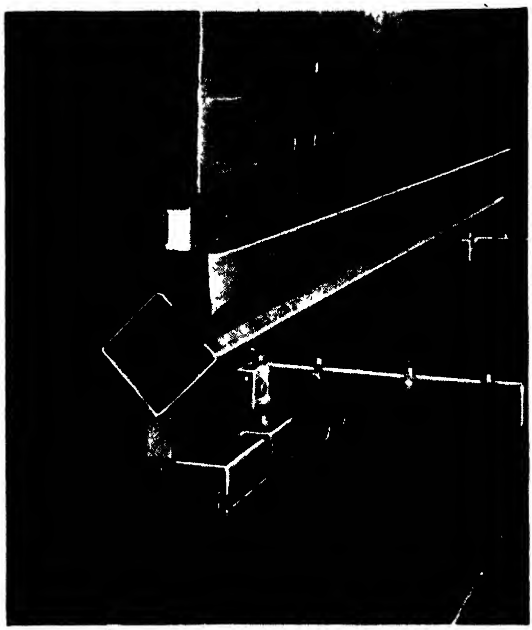


Cincinnati Shaper Co.

Fig. 20-12. Four-way Die.

beginning with the two right-angle bend operations in the die at the left; the central die produces the sharp central bend; and the die at the right closes this bend to form the tee-shaped section. This set-up enables an operator on one brake to handle work which might otherwise require several machines and handlings. These operations are accurately performed with the aid of adjustable stops and gages.

Fig. 20-16 shows a patented process for producing flattened tubes without using dies or any special equipment. This is accomplished by inserting rods in a cylindrical section, and applying pressure through the press ram to flatten the circular section until the tubing has assumed the shape dictated by the rods. The pressure is then released and the rods are withdrawn. The rods should be lubricated with grease or machine oil but can be used



Cincinnati Shaper Co

FIG. 20-13. Goose-neck Die.

Cincinnati Shaper Co

FIG. 20-14. Folding a Tee-shaped Section on a Press Brake.

over and over. Selection of the right number and size of rods is essential to satisfactory results.

281. Press brakes may also be used for **multiple punching operations** on sheet metal parts such as automobile body sections and railroad car sides and tops. The punches are carried in blocks which are bolted to a head attached to the brake ram; any individual punch or series of punches may be rendered inoperative for a particular stroke by the hand actuated gags at the front of the head. Stripper bars are placed at intervals between the punches. The separate die blocks are bolted to the bed of the brake in alignment with the punches. The hole spacing may be altered by shifting the punch and die blocks, and the set-up may thereby be adapted to a wide variety of work.

282. Multiple-slide machines are used for complex bending and forming operations on wire and narrow strip stock. Fig. 20-17 illustrates the sequence of operations and the plan view of a **four-slide wire-forming machine.** The machine has a horizontal bed on which four slides that carry forming dies *A*, *B*, *C*, and *D* move as indicated. A fifth slide *F* can move vertically and carries a shape die—in this case a pair of pins—about which the part is formed. A fixed stripper plate is placed so that the motion of *F* will remove the work from the pins. The machine is also equipped with a wire feeding device *E*, and a separate slide carrying a shear blade *J*. All these slides are actuated by grooved face cams, so designed that one set of cams will serve for the usual variety of work by proper setting and timing. A newly-designed part therefore requires only a set of dies *A, B, C*, and *D*, and a shape die, all of which are comparatively easy to make.

Fig. 20-17, *M*, shows the wire *W* fed to a stop, and the shear *J* moving forward in synchronism with the die *D* so that *D* clamps the wire against the pins and, as the wire is cut, effects the first bending operation. Dies *B* and *C* then curl the ends, and die *A* completes the forming operation as illustrated at *P* and *Q*. The slide *F* then moves vertically downward stripping the completed part from the pins. Slide *F* moves up again, the other dies return to the position shown at *M*, and the cycle is complete.

Machines of this character are used for a wide variety of parts such as rings, links, hooks, clips and other parts formed cold from wire and strip steel. **Multi-slide strip machines** are also used for combination manufacturing and assembling purposes; a hinge machine, for example, blanks the hinges from strip stock, punches the holes, slits and forms the pin bearings, and inserts the hinge pin, producing a completed hinge automatically.

283. Drawing and allied press operations are used primarily for producing cup-shaped parts from flat blanks. Fig. 20-19 represents a comparatively simple **drawing die,** in which a blank *N* is placed in a recess

of the correct size in die L and forced through the hole by a punch P. Fig. 20-20 shows several stages of operation of a **redrawing die.**

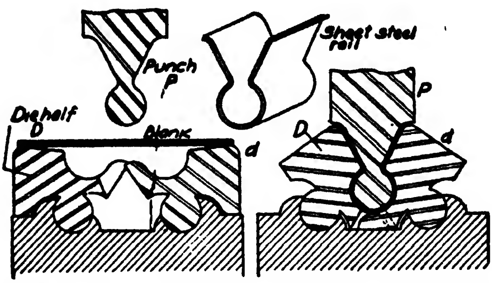


FIG. 20-15. Single-operation Press Brake Die for Forming Sheet Steel Rail.

In these operations the end of the punch is rounded so that no cutting takes place. If the space between the punch and the hole in the die is

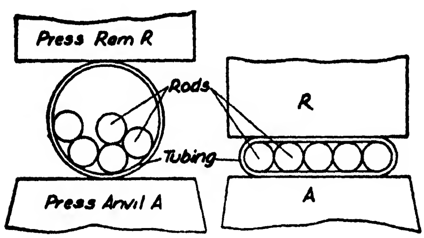


FIG. 20-16. Tube Flattening Process.

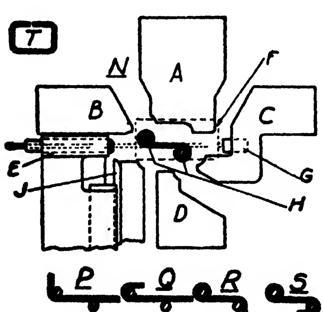


FIG. 20-18. Forming a Link on a Multi-slide Machine.

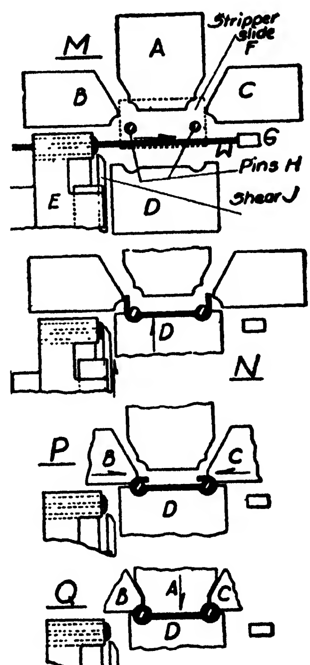


FIG. 20-17. Sequence of Operations on Multi-slide Machine.

sufficient to allow for the full thickness of the metal, there will be no reduction in thickness, and the area of the cup will be about the same as the

original area of the blank. The blank is subjected to tension on account of the punch action and to compression by virtue of the reduction in its outer circumference. For a large depth of draw, these forces may produce

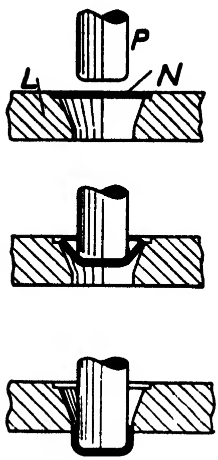


FIG. 20-19. Single-action Cupping Die.

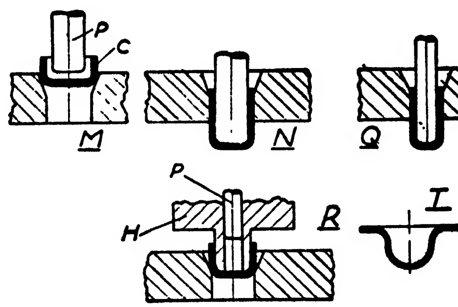


FIG. 20-20. Redrawing Operations.

wrinkles in the outer portion of the blank. To eliminate this possibility, the edge of the blank is held between a pressure pad or blank holder *B* and the die *L*, Fig. 20-21. The pressure exerted must not be too great or the part

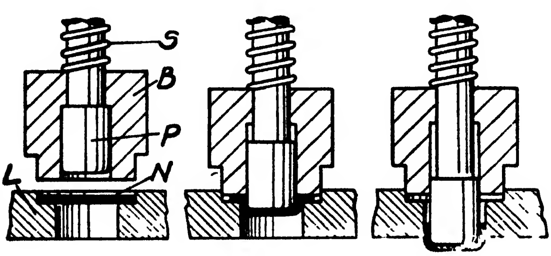


FIG. 20-21. Single Action Cupping Die with Blank Holder.

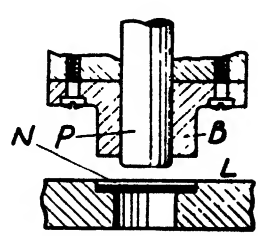


FIG. 20-22. Double Action Cupping Die and Blank Holder.

may be torn by the action of the punch *P*. Fig. 20-22 shows a similar cupping die for use in a double action press.

Parts are generally ***redrawn*** whenever the ***depth of draw*** exceeds one-half the diameter of the cup. In Fig. 20-20, *M* shows the cup *C* of Fig. 20-19 in position, *N* shows the first and *Q* shows a second redrawing operation. As it is often difficult to position the part properly in the die, a

blank holder *H*, as illustrated at *R*, is used for accurate redrawing. *H* must be spring-actuated if it is used in a single action press.

284. In making redrawing dies or in the design of any series of dies that perform successive operation on a part, the final die is generally made first and operated with hand-formed blanks, if necessary, to study the behavior of the metal, to determine the number of draws, and to gage accurately the size of the blank. A great deal of practical as well as theoretical data is available on die design and manufacture, but complicated dies, or any new die series, may offer specialized problems for which trade practice offers no specific solution.

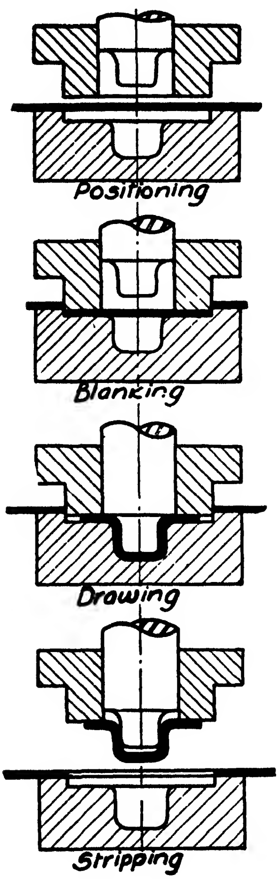


Fig. 20-23. Combination Blanking and Drawing Die for Double Action Press.

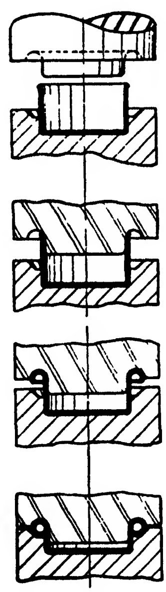


Fig. 20-24. Curling Die Operation.

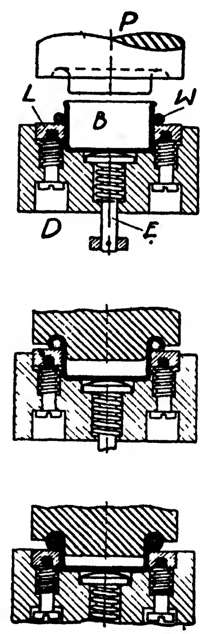


Fig. 20-25. Wiring Die.

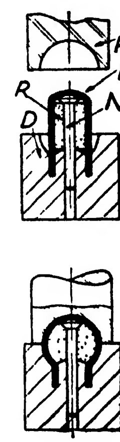


Fig. 20-26. Bulging Die with Soft Rubber Insert.

285. Fig. 20-23 shows a **combination blanking and drawing die** used on a double action press, in which the blanking die serves as a blank holder while the drawing operation proceeds, and as a stripper for the finished part as the punch is retracted. This die is more expensive than separate blanking and drawing dies but is more economical in operation.

Reducing dies are used for necking the open ends of drawn cups in such applications as cartridge case manufacture. **Curling dies,** illustrated in Fig. 20-24, are used for curling or rolling a flange or bead around the open edge of a cup. The cup should be slightly flanged in its final draw to permit the curling punch to start easily. **Wiring dies,** shown in Fig. 20-25, are used for curling and simultaneously enclosing a wire ring W inside the flange. The wire is carried by a spring plate L which recedes to permit the metal to be rolled entirely around the wire. This die is equipped with a spring-actuated stripper pin E for automatic ejection of the part from the die.

Bulging dies are special drawing dies that use either a soft rubber pad R, as illustrated in Fig. 20-26, or a fluid such as oil, Fig. 20-27. They are used for articles that are not straight-sided or tapered inwards. In the **hydraulic die,** the oil within the blank N is compressed by the ram P so that it forces the blank to conform to the interior of the die. The die is made in two parts, a stationary half D and a movable half M, so that it may be opened to permit the finished part to be removed. An oil hole H is provided in D so that the oil within the closed die may escape as the blank expands.

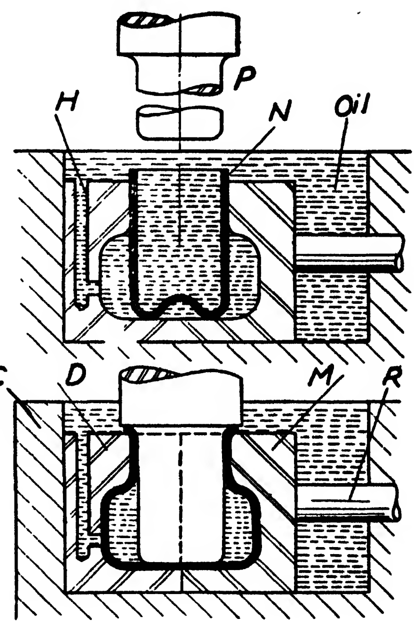


FIG. 20-27. Hydraulic Bulging Die.

286. Metal spinning is a specialized drawing operation employed for articles which have surfaces of revolution. Metal spinning is usually employed for small-quantity production where the number of parts required does not warrant the use of a drawing die; the process is also used for shapes which are difficult or impossible to produce in dies.

Metal spinning lathes are similar to engine lathes. The spinning tool may be either manually or mechanically guided. Fig. 20-28 illustrates the sequence of operations A to E in **spinning a cup** with a curled edge. A wooden (or metal) form G is fastened to the face plate of the spinning lathe, and the sheet disc is placed against it and held in position by a rotating tail center T. The material is shaped by forcing the spinning tool U against

the work as it rotates. The shank of the tool pivots about a stop S in the tool rest.

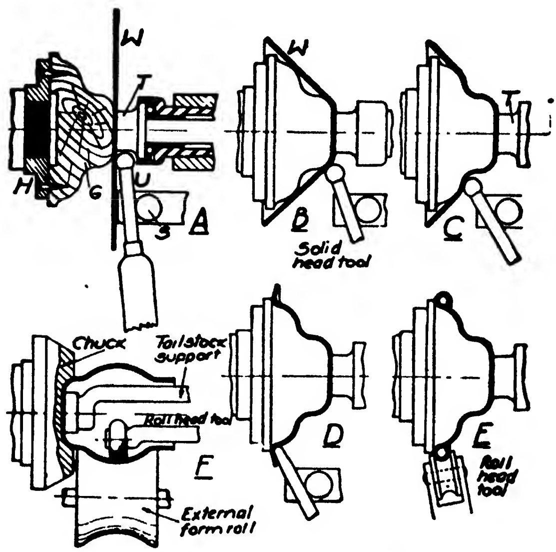


Fig. 20-28. Metal Spinning.

Spinning tools may have solid or roll heads. Internal spinning may be effected by using an external form roll as illustrated at F, for forming shapes that might otherwise require a bulging die for their manufacture.

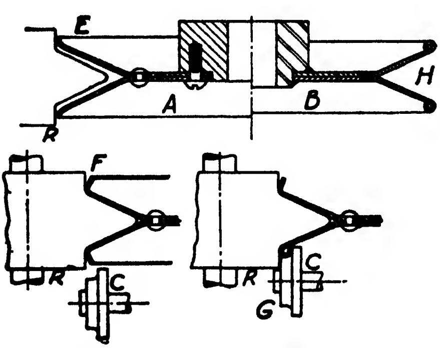
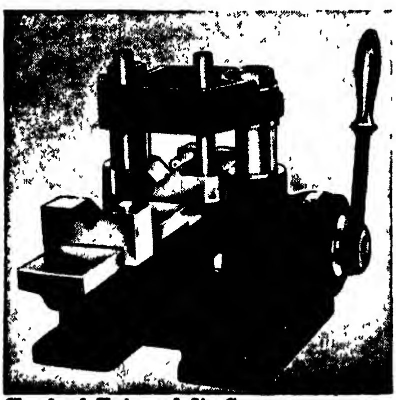


Fig. 20-29. Flanging a Vee Belt Sheave Groove.

Fig. 20-29 shows a method of spinning or curling the edges of a **vee-belt sheave.** This is accomplished in a **seaming machine** in which the work is held on a vertical rotating spindle, and the curling rolls R and C are carried by an arm that swings in a horizontal plane. The successive stages are illustrated at E, F, G, and H. The illustration also shows the difference between **two modes of sheave construction.** Construction A shows the two sheave halves as they are received from the drawing die, riveted together and attached to a cast iron hub by screws. Con-

plate A, made to fit the projecting lugs on the bearing cap, is screwed and dowelled to the jig base. A stop C serves to locate the work axially. The work is held down by pin P in the top plate R of the jig. The top plate is bored to suit the guide bushings S, which serve to locate bushings B for drilling and bushings E (not illustrated) for counterboring. These bushings have knurled heads and are held in place by the shoulder screws T as illustrated. Without these screws, the drill bushings would probably rotate or "work" out of the guide bushings as the drill rotated.

In operation, the handle H is initially in a vertical position so that the top plate R is high enough to permit insertion of the work. The handle is then brought down, clamping the work between A and P. The screw



Cleveland Universal Jig Co.

FIG. 21-5. Shaft and Bar Drilling Jig.

Consolidated Machine Tool Corp.

FIG. 21-6. Universal Joint Flange.

body holes in the bearing caps are drilled using bushings B; these bushings are removed by turning them 45° in a counterclockwise direction and lifting them out of the guide bushings S. Bushings E for guiding the counterbore are then inserted, the holes are counterbored, and the top plate is lifted and the work removed, completing the cycle of operations.

Fig. 21-5 illustrates a **semi-universal jig** for drilling cross holes in shafts and bars. The jig consists of a frame similar to that of Fig. 21-3, and is fitted with an adapter which carries one sliding vee, one stationary vee, and an adjustable work stop. The bar to be drilled is placed in the vees and is clamped by lowering the top plate. The top plate carries a guide bushing which will accommodate a variety of drill bushings similar to B, Fig. 21-4, so that holes of various sizes can be drilled. This jig is adapted to unit-production as well as mass-production operations, since the top plate has a vertical movement sufficiently great to handle a variety of shaft sizes.

The drill jigs shown in Fig. 21-3; 21-4, and 21-5 cannot be conveniently applied when it is necessary to turn the jig to drill holes whose axes are perpendicular or at an angle to each other. They are extensively used in industry however, not only because the cost of a built-up jig is often less than a jig which is completely constructed in the tool room of a manufacturing organization, but also because it is often possible to use a single

Consolidated Machine Tool Corp.

FIG. 21-7. Drilling and Reaming on a Universal Joint Flange.

frame for several parts or operations by replacing the adapter plates and bushings.

Many manufacturing organizations also find it more profitable to purchase drill and guide bushings. Renewable slip bushings such as *B*, Fig. 21-4, bushings with heads similar to *B*, Fig. 21-1, and guide bushings, are carried in stock in sizes from $\frac{1}{16}''$ to $1\frac{3}{4}''$ inside diameter, and vary in price from one to four dollars each.

296. The drill jigs of Fig. 21-1 and 21-2 are generally used with **single-spindle upright drilling machines** such as those of Fig. 9-22 and Fig. 10-2. **Two drill presses** like the one shown in Fig. 9-22 may be mounted on one base and used in conjunction with the jig of Fig. 21-2. One machine would be used for drilling the two main holes, the other for the oil hole. Another method of handling this work would be to construct a **special base to hold three columns and heads** like those of Fig. 9-22; two of the heads would be set so that the distance between the drill axes would equal the center distance of the connecting rod holes. In such a procedure, drill spindles with power feeding mechanisms would probably be used.

Fig. 21-7 shows a **two-spindle manufacturing type drill press** which has both heads equipped with two-spindle multiple drill heads for drilling and reaming two $\frac{11}{16}''$ diameter holes, $\frac{7}{8}''$ deep, in the universal joint flanges illustrated in Fig. 21-6. In these operations, two jigs, one for each operation, are clamped to the drill press table. Each spindle of the drill press is equipped with an independent power feed, not only to enable varying rates of feed for drilling and for reaming to be obtained, but also to permit the operator to load and unload one fixture while the work in the other is in process. Drill bushings are used for guiding the drill during the operation, but floating reamers similar to those of Fig. 10-32 or 10-33 are used for the finish-reaming operation. A production rate of 80 drilled and reamed parts per hour is attained.

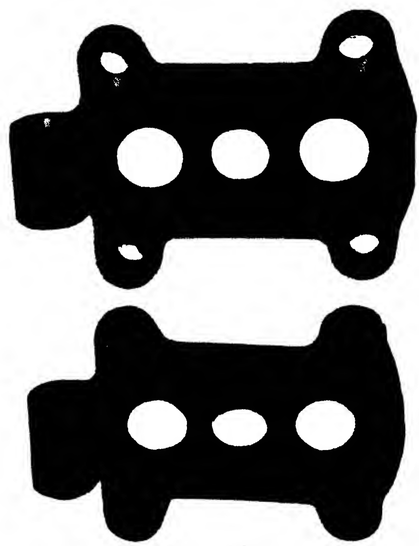


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FIG. 21-8. Automobile Spring Clamp.

The **multiple drill heads** illustrated in Fig. 21-7 have a driving shaft with a tapered shank which fits the tapered hole in the drill *press* spindle. This shaft drives the spindles of the multiple drill *head* by means of spur gearing. The housing of the drill head is attached to the spindle sleeve of the drill press, and is sometimes aligned by guide columns in the drill jig itself, as illustrated in Fig. 21-9. This illustration shows a **two-spindle gang drill** for drilling five holes in the automobile spring clamp shown in Fig. 21-8. The spindle at the left carries a **single drill** for originating and finishing the hinge hole in the clamp; the

work is located by the cored holes, and is clamped by a screw with a *star* knob and by the threaded drill bushing. The spindle at the right is equipped with a **four-spindle multiple drill head** for drilling the bolt holes in the work; the part is located in the jig by the drilled hinge hole. A **leaf-type drill jig**, with a clamping eye-bolt that may be swung away from the

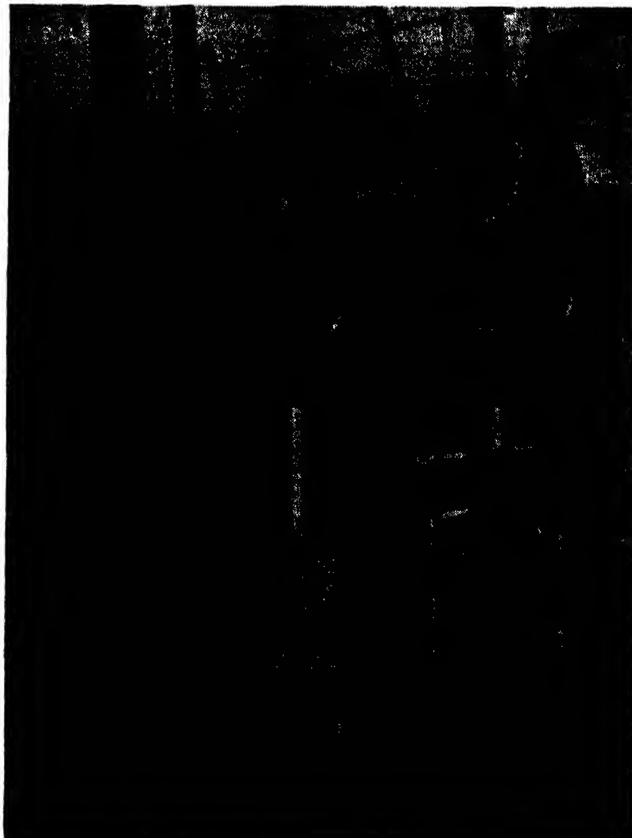

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FIG. 21-9. Drilling Operations on an Automobile Spring Clamp.

leaf, is employed for holding the work. The production rate is 25 finished pieces or 125 drilled holes per hour.

297. In the drilling operations of Fig. 21-7 and 21-9, the drill jigs are fastened to the drill press table, and are in permanent alignment with the spindles. It is therefore possible for the operator to insert and clamp the work in the jig, start the power feed of the drill, and then give his attention to another operation. This procedure, however, requires **relocation**

of the part in another jig for subsequent operations. In general, this procedure is less expensive from the standpoint of labor cost but it requires additional jigs for each set of holes. It would be feasible, of course, to design a jig for drilling all the holes in the part of Fig. 21-8 by locating and clamping the part once, and turning the jig on its side for drilling the bolt holes after the hinge pole has been drilled. The universal joint flange of Fig. 21-6 could, in an analogous manner, be held in a drill jig equipped with guide and slip bushings, so that the two holes could be drilled and then reamed by using a replaceable set of bushings. The *single jig* procedure has one further advantage: it eliminates possible location errors which may occur when a part is removed after drilling one set of holes and relocated in another jig.

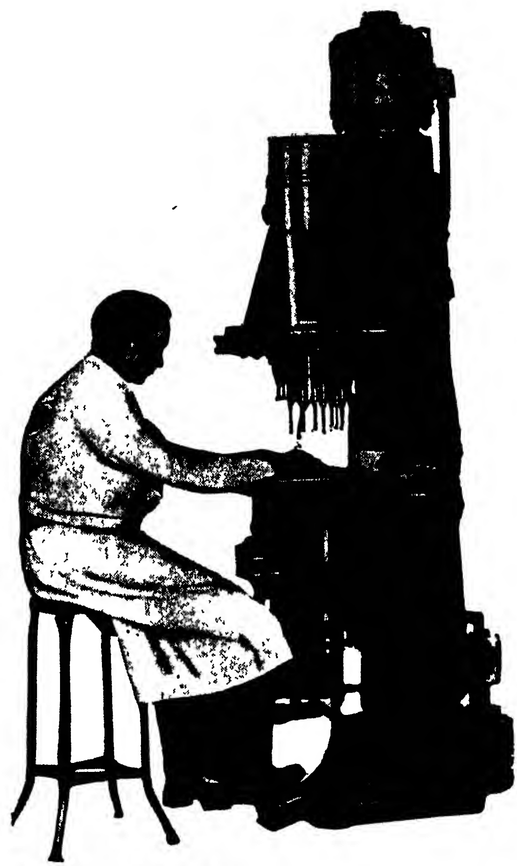

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Fig. 21-10. Multiple-spindle Drilling Machine.

Two-spindle gang drills with three-station **indexing tables** are also available. Such a machine can be used for drilling and reaming the holes in the universal joint flange of Fig. 21-6. The table is equipped with three fixtures, of which two are in the operating position underneath the two spindles at any one time. Instead of having guide bushings in the work-holding fixture, the multiple drill heads on the drill press spindles are equipped with a jig plate which moves down as the spindles feed. The third station at the front of the spindles is used for loading and unloading, and the table is hand indexed to position as each operation is completed. In this arrangement, the parts are drilled and reamed without removing them from the jigs, and as the drilling operation

requires about twice the time used for loading and unloading, one operator is able to handle two machines.

298. Fig. 21-10 shows an upright drilling machine with a **multiple-spindle head** and an hydraulically-actuated power feed table. The table moves vertically on two cylindrical guides attached to the column of the machine and is controlled by a foot-operated air valve. When the operator depresses or opens the valve, the table moves rapidly up, and then feeds up; release of the valve causes the table to drop rapidly to the starting

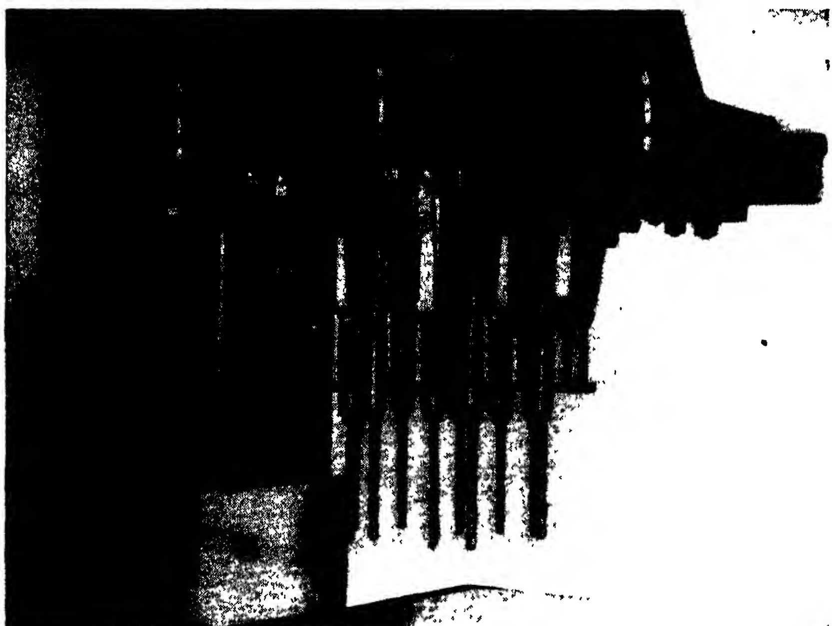

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FIG. 21-11. Adjustable Multiple-spindle Drilling Head.

position and stop. When the machine is used for tapping, the table travels through an automatic cycle as follows: rapid up; feed up; feed down; rapid down to starting position; stop. The direction of rotation of the spindles is reversed at the instant the upward feeding motion ceases; the downward feed, in conjunction with the reversal of the spindle rotation, screws the tap out of the threaded hole. The machine may also be equipped with a manual feed controlled by a hand-operated lever.

Fig. 21-11 shows a detail view of a **ten-spindle head** which is similar to the head of the machine of Fig. 21-10. Fig. 21-12 shows a sectional

view of the spindle and arm. The spindle S rotates in two bushings U which are carried in a spindle housing H. The housing is clamped to arm A by a clamp bar C; vertical adjustment of the housing with respect to the arm is obtained by turning screw W. The spindle is driven from a change gear

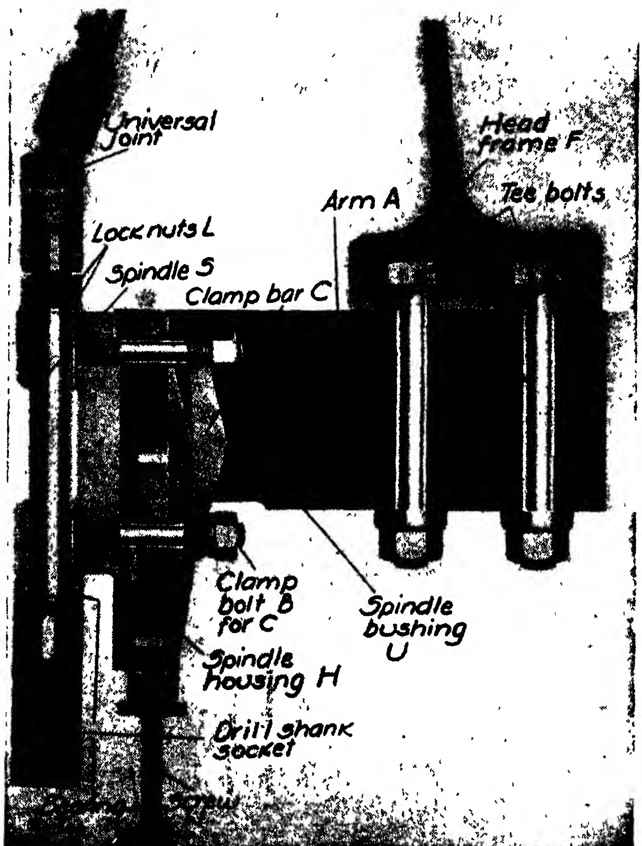

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Fig. 21-12. Construction of Spindle and Arm of Adjustable Multiple-spindle Drilling Machine Head.

box at the top of the head by a shaft and two universal joints; one of these joints is shown in Fig. 21-12 (and is shown disassembled in Fig. 3-15). The arm A which carries the spindle housing may be adjusted for various center distances, and can be locked to the head frame F in almost any position by the tee-bolts shown. It is therefore possible to set the ten spindles in a wide variety of center to center positions, limited only by the clearance

necessary between the spindles and arms and by the extent of the head frame clamping surface.

The spindle S has a ball thrust bearing T at its lower end to take care of the drilling thrust, and two lock nuts at the upper end to compensate for vertical wear. Standard spindles may be used either for drilling or for tapping; when a spindle is used for **tapping operations,** it is provided with an arrangement which permits approximately ¼″ of vertical movement or float, entirely independent of the table feed.

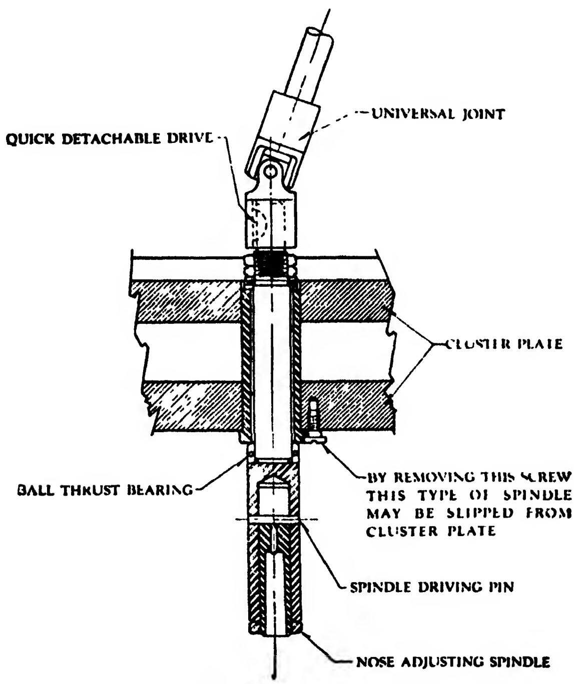
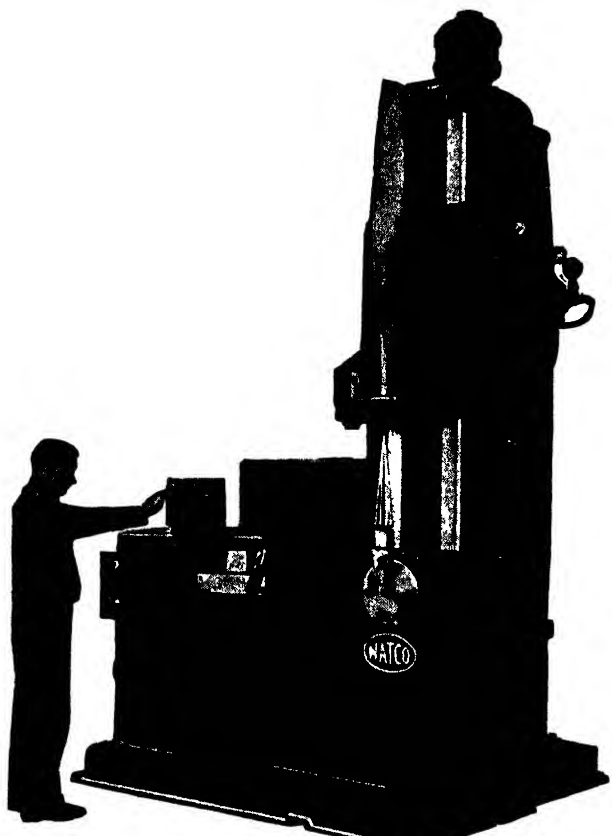


Fig. 21-13. Cluster-plate Spindle Construction.

Equipment of this character is of course special-purpose machinery, and as such, is rarely if ever used in the unit-production system of manufacture. On the other hand, the adjustable arm feature of the multiple-spindle drilling machine makes it possible to adapt this unit to a variety of operations at a minimum expenditure of time and labor.

299. Fig. 21-13 shows another type of multiple-spindle drilling head. **Cluster-plate construction** is used for short center distances where holes are close together, and is particularly advantageous on machines requiring several setups which must be frequently changed from

one to another on account of a limited production. The cluster plate, which may contain holes for several operations, is bolted to the underside of a head frame similar to that shown in Fig. 21-11, and serves as a support for the spindle quill in which the spindle rotates. The spindle is driven by a keyed universal joint at the end of a shaft from the change gear box at the top of the head frame. The entire spindle unit in the quill can be re-

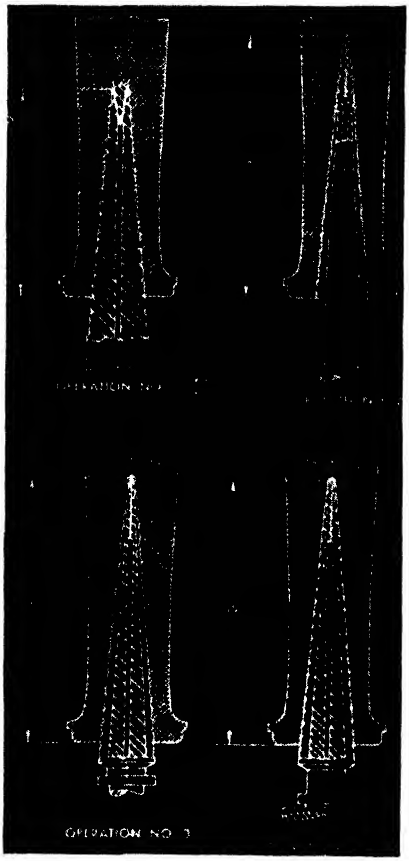


National Automatic Tool Co.

Fig. 21-14. Reaming the Hole in an Adjustable-pitch Propeller Blade.

moved from the cluster plates by removing a shoulder screw. This spindle assembly can then be placed in another hole in the cluster plate, and the machine is again ready for operation after the screw has been replaced. The spindle is equipped with a slip sleeve which can be adjusted vertically to compensate for differences in drill lengths after grinding.

300. Fig. 21-14 illustrates a **deep hole drilling machine which is used** by a prominent manufacturer of adjustable-pitch propellers. The machine is used to drill, rough ream, and finish ream the large tapered hole in the hub end of aluminum alloy propeller blades. The work is mounted on a fixture attached to a vertical traversing slide. The cutters are mounted in a vertical spindle in the bed of the machine. In operation, the operator places the work in the fixture, and the traversing slide moves downwards rapidly and then feeds to the correct depth; the slide then rises rapidly and stops while the operator changes the tool. Four separate operations are required to produce a finished hole, as illustrated in Fig. 21-15. In operation 1, the hole is taper-drilled to partial depth with a special stepped tool. In operation 2, the remainder of the hole is step-drilled. Operation 3 shows the rough reaming operation, while operation 4 shows the finish reaming operation in which a special tapered reamer is used. The cutting edges are lubricated by a coolant or lubricant which is pumped through the hollow vertical spindle of the machine, up through the central hole in the tools and out through the holes in the tip.

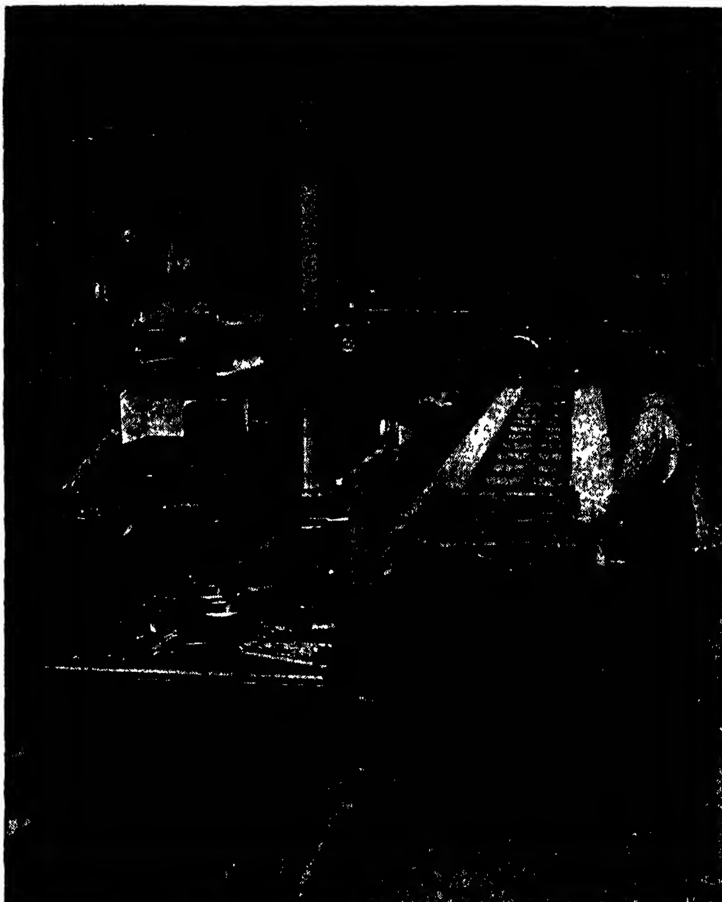


National Automatic Tool Co.

Fig. 21-15. Sequence of Operations in Drilling and Finishing a Tapered Hole in a Propeller Blade.

301. Fig. 21-16 shows how a comparatively **small drill jig** may be applied to **large work.** The part to be drilled is a lathe bed 42" by 252", in which eight $1\frac{5}{8}$" diameter—5" deep holes, twenty-nine $\frac{1}{2}$" diameter—3" deep holes, and sixty-two $\frac{5}{8}$" diameter—3" deep holes are drilled; twelve $1\frac{3}{8}$" holes are drilled and faced to a diameter of $2\frac{7}{16}$"; and twelve $1\frac{1}{4}$" holes are drilled and tapped. and faced to a diameter of $2\frac{3}{16}$". The entire series of operations is accomplished in twelve and one-half hours, and all holes are held to size and

location within plus or minus .001". The machine is a standard radial drill mounted on a track-type base so that the machine may be moved to accommodate the work. The drill jig is clamped to the surface of the

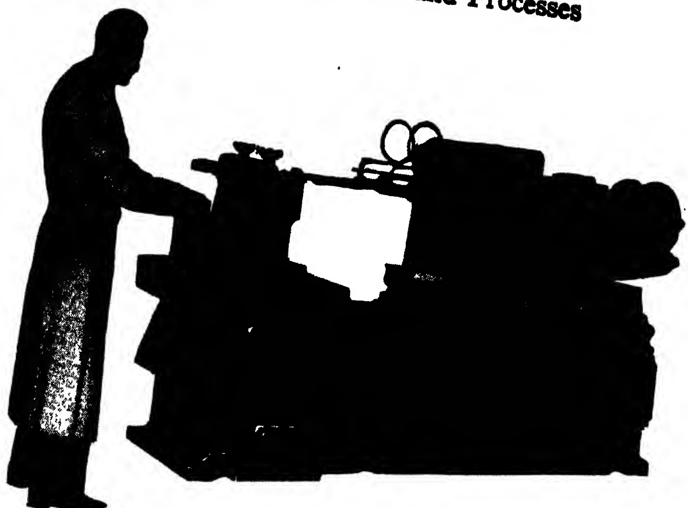


Cincinnati Bickford Tool Co.

Fig. 21-16. Using a Drill Jig with a Radial Drill.

work as illustrated. A number of drills and other tools that are used in this process may be seen on the base of the machine.

302. Fig. 21-17 shows a **special machine** for reaming the lightening holes that are drilled in the shank of an airplane engine connecting rod. The machine consists of a motor-driven hydraulic feed and traverse unit which



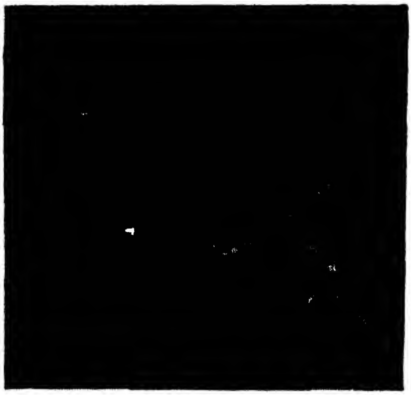
National Automatic Tool Co.

FIG. 21-17. Reaming the Lightening Hole in an Airplane Engine Connecting Rod.

Chrysler Corporation

FIG. 21-18. Boring and Reaming Operations on Engine Blocks

moves on a slide mounted on a machine bed, and a fixture for holding two connecting rods. The spiral reamers have oil holes through their bodies, and the lubricant is pumped through the coiled tubing to the cutting edges.



Heald Machine Co.

FIG. 21-19. Boring Head.

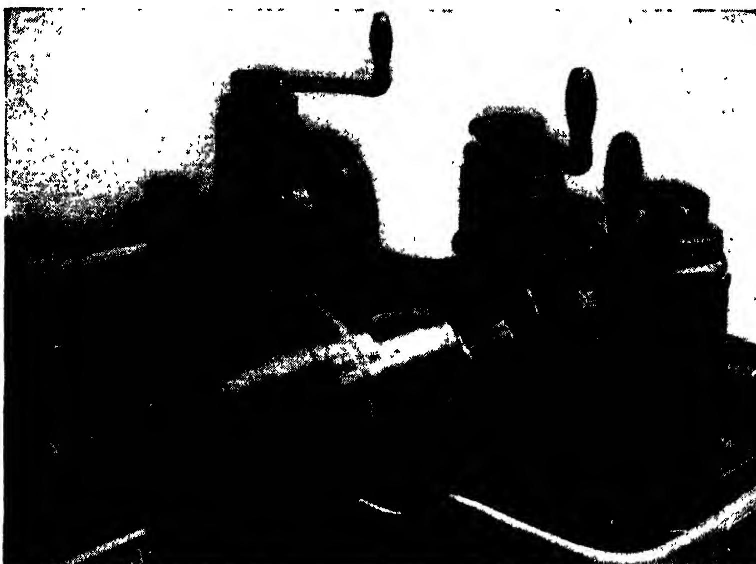
Special machines for drilling or reaming holes from two or more sides of a part can be constructed by attaching similar slides and units to a suitable machine bed. One machine of this character is illustrated in Fig. 21-18, which shows a **multiple-station, multiple-spindle machine** for boring and reaming the cylinder bores and the valve tappet parts in a six cylinder automobile engine block. In this process, the blocks are brought to the machine by a roller conveyor, and one operator loads the fixture at the loading station, while another unloads the finished blocks.

Heald Machine Co.

FIG. 21-20. Boring Wrist Pin Holes in a Piston.

303. Horizontal spindle boring mills of the type shown in Fig. 12-24 are extensively used for mass-production precision boring operations. Many boring and facing operations, particularly for short holes of small diameter, can be more readily handled, however, on smaller machines that are simpler and are easily adapted to special jobs.

304. Mass-production boring machines consist of a bed on which one or more boring heads like that of Fig. 21-19 are mounted. The bed also carries a horizontal table which moves in a direction parallel to the boring



Heald Machine Co.

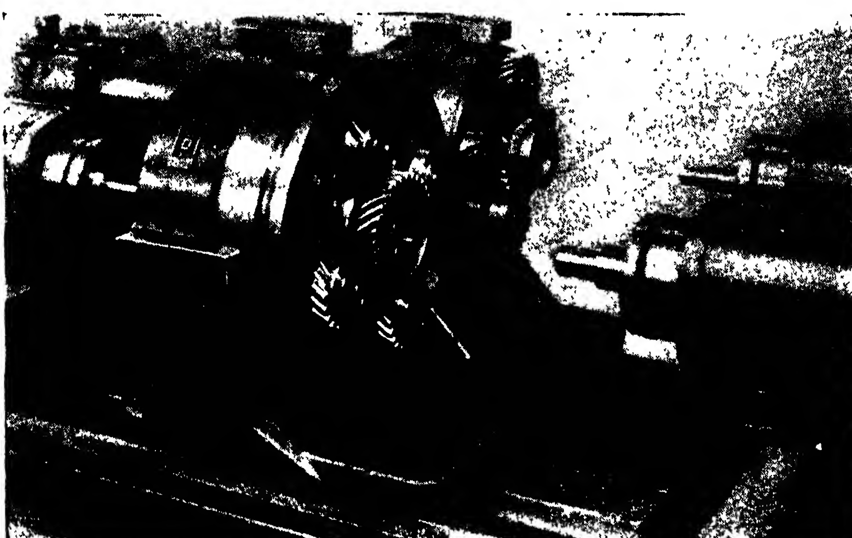
FIG. 21-21. Boring Connecting Rod Holes.

head spindles. The table is hydraulically actuated, which permits a rapid advance, a feed motion, and a rapid return to the starting point. The machines are generally equipped with automatic trips so that the operators' duties are reduced to unloading and loading the fixture, and starting the machine by pressing a pushbutton. The spindle in the boring head is driven from a motor by four vee-belts, and is carried on four preloaded ball bearings.

The spindle is equipped with an adjustable offset boring head so that the tool bit in the projecting bar can be set very accurately by using the graduation on the outside of the spindle. Each graduation indicates a difference of .0002" in the diameter of the hole bored. Boring tool bits for mass-production operations generally consist of tungsten-carbide or diamond

Heald Machine Co.

Fig. 21-22. Boring Eight Cylinders Simultaneously.

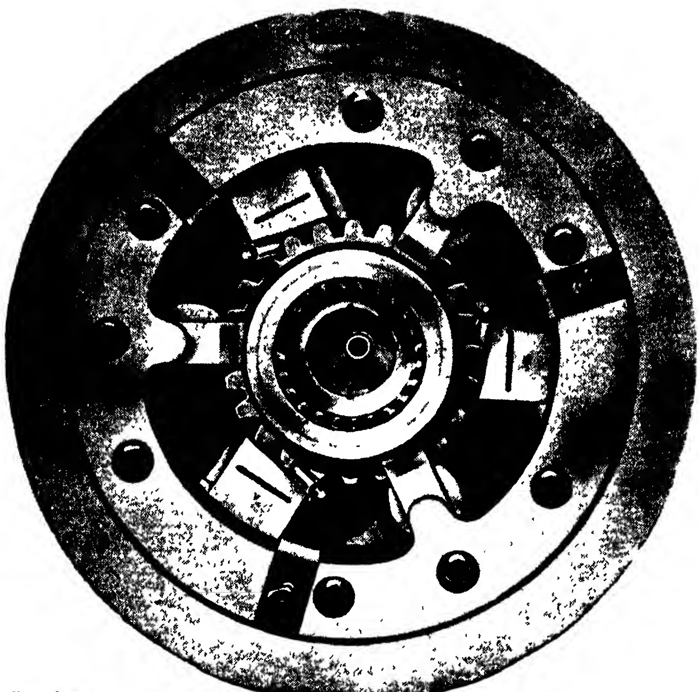


Heald Machine Co.

Fig. 21-23. Boring Cluster Gears on a Double-end Boring Machine.

tips set in shanks which fit the hole in the boring bar. These materials are used not only because they increase production rates, but also because they require very little attention or resharpening after they are set.

Fig. 21-20 shows a boring machine set up with two boring heads and two fixtures for boring and finishing the wrist pin holes in a pair of engine pistons. The pistons are located in the fixture by placing them over a plug which fits the inner diameter at the bottom of the skirt, and the



The Cima Tool Co.

Fig. 21-24. Gear Chuck.

wrist pin holes are properly aligned by inserting a centering plug, shown lying on the table of the machine, through a bushed hole in the rear of the fixture, and then through the drilled wrist pin holes. The piston is clamped by a cam-actuated hand clamping device at the top, and the centering plug is then removed and used for locating the other piston.

Fig. 21-21 shows a semi-universal fixture which is adjustable so that connecting rods from 12″ to 18″ center distance may be held in it. The work is located from pads underneath the rod at each end, and from a boss at the wrist pin end. Three hand operated clamps hold the rod against the crank

hole face, wrist pin hole face, and also transversely against the wrist pin end. Two boring heads are employed: one for boring the 3¼″ babbitt lined crank hole, and the other for boring the 2″ bronze bushed wrist pin hole.

Fig. 21-22 shows how **eight cylinders** in an Oldsmobile straight-eight engine block **are bored** by using eight parallel boring heads. The work is transferred from a conveyor to an auxiliary fixture slide where it is then carried hydraulically up into the fixture. The block is located from the crankshaft holes and hydraulically clamped. The boring operation results in eight holes that are accurate within an allowable error of .0002″ for roundness and straightness. Machines of this character are sometimes equipped with boring heads at either end of the table so that work may be precision-bored from both ends. Fig. 21-23 illustrates how **three** bronze-bushed **gear units are simultaneously bored** on a machine of this type. The fixture or chuck in the foreground holds a cluster gear which is bored from both ends by two opposed heads. The chuck at the rear holds two gears, one on each face, so that each gear may be bored by a separate head. Each gear is located and held in place by four helical pinions mounted on the faces of the fixtures.

Fig. 21-24 ~~illustrates another type of gear chuck~~ which is used for holding helical gears while boring or grinding the shaft hole. The chuck has three radial jaws each of which carries a pin which fits the tooth space of the work. Each pin is set at an angle equal to the helix angle of the gear. These methods of holding gears are used for spur as well as helical gears, and insure concentricity of the pitch circle and the bore so that smooth, noiseless gear operation may be obtained in assembly and in service.

CHAPTER 22

PRODUCTION TURNING AND FACING PROCESSES

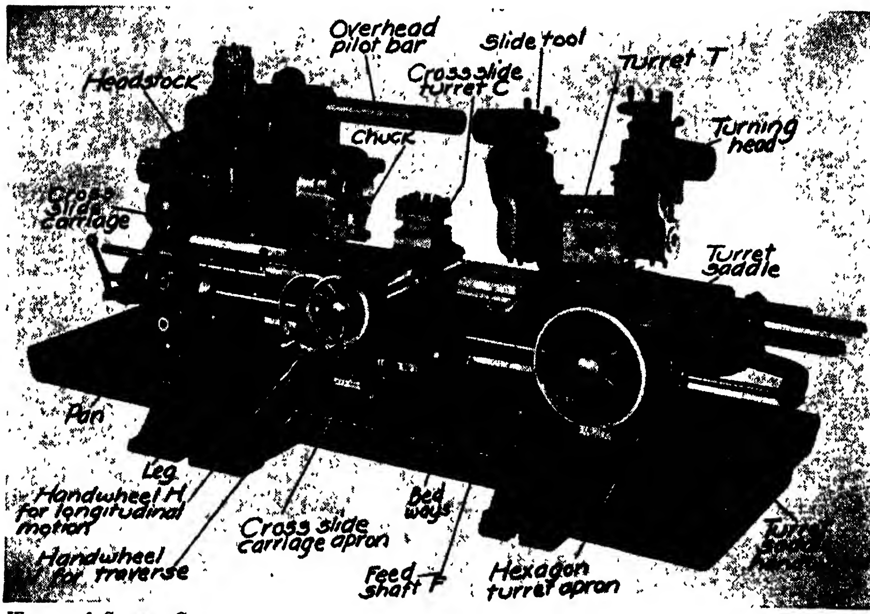
305. Mass-production turning and facing equipment may be classified as hand-operated, semi-automatic, and completely automatic machinery. **Hand-operated equipment** generally requires the attention of an operator while the work is in process; **semi-automatic equipment** usually requires an operator to load and unload the parts to be machined, after which the machine performs a cycle of operations and stops at its conclusion without further attention; **automatic machinery** requires no service from the operator except gaging the parts as they are produced, resharpening and resetting the tools when required, and filling a hopper with blanks, or in the case of bar machines, inserting fresh bar stock when the original bar has been processed. To illustrate, one operator is required for every turret lathe in use; one man can handle from two to four semi-automatic chucking machines; but six or even more automatic screw machines can, in some instances, be taken care of by a single operator.

306. Turret lathes are used in the mass-production system of manufacture to care for the wide, diversified field of production between the engine lathe on one hand, and the automatic or semi-automatic bar and chucking machine on the other. It may be recalled from Chapter 11 that parts which were machined in an engine lathe by being held in a chuck could be drilled and reamed by using tools held in the tailstock sleeve; and that the part was subsequently bored, turned, and faced by a series of tools held in the tool post. Turret lathes operate on precisely the same principle. The single hole tailstock, however, is replaced by a six-station turret which holds six tools of such character that from six to fifteen cutting and finishing operations may be successively performed on the part without the necessity of changing the tooling equipment; and the single operation tool post is replaced by a four or six-station turret which permits four or more cross slide turning and facing operations.

307. Fig. 22-1 illustrates a modern **turret lathe** with a six-station turret T for end-cutting operations, and a four-station cross slide turret C for side-cutting. The machine has an all-geared headstock, similar to that of a modern engine lathe, and a carriage which carries turret C and is free to move on the bed of the machine parallel to the spindle axis. The bed also supports and guides the turret saddle which carries the turret T. Both the turret saddle and the cross slide carriage may be power fed longi-

tudinally or parallel to the spindle axis; the cross-slide can also be power fed at right angles to the spindle. The feed change gears are arranged in a gear box attached to the headstock, and the cross slide and saddle are driven by shaft F. The turret saddle can also be rapidly traversed by power.

In operation, the work blank is clamped in the chuck, and the operator starts the machine and brings the first face of the turret to the work, either by power or by using the turret saddle handwheel. He then engages the power feed for the saddle and permits the tools at the first



Warner & Swasey Co.

Fig. 22-1. Saddle-type Turret Lathe with Three-jaw Universal Chuck.

station to operate while he brings the carriage into longitudinal position by handwheel H. The cross slide is adjusted on the carriage by the cross-feed handwheel I', and the power feed is engaged for either the carriage or cross-slide as required. If the operation at the first turret station is complete at this time, the operator moves the turret saddle to the right away from the work. The conclusion of this return motion indexes the turret to the second station, so that it may again be brought to the work and fed by power for the next operation. The turret C is then indexed by hand and locked so that its second set of tools can be applied to the work. This procedure continues until the part is finished. Adjustable stops for tripping the carriage and the turret saddle feeds at the conclusion of the cut are

provided so that the operator can index or position one unit **without any** danger of feeding too far on the other.

308. Fig. 22-2 illustrates the essential principle of **operation of a turret** which indexes in a horizontal plane. In the mechanism illus-

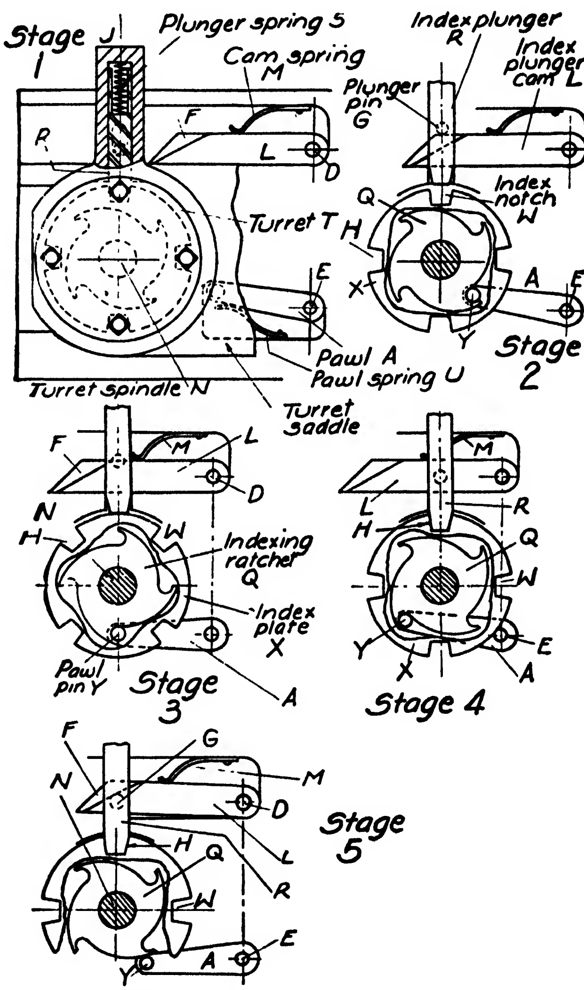


Fig. 22-2. Principles of Turret Indexing Mechanism Operation.

trated, the cylindrical four-station turret T is mounted on a vertical spindle N, that rotates in suitable bearings in a turret slide or ram which has rectilinear freedom on the ways of the lathe. An indexing ratchet Q and an index plate X are fastened to the spindle N. An index plunger retracting

cam L and a pawl A are pivoted at D and E, and are seated in recesses in the bed of the lathe. The cam L has a projecting lug F, and the plunger R carrying a projecting pin G, so arranged that the pin G clears the body of the cam but contacts the lug F. The pawl A has a projecting pin Y to engage the ratchet Q. L and A are held in position against the inner edges of the recesses in which they lie by leaf springs M and U. The turret is locked in position by the index plunger R, which is seated in notch W in index plate X by the action of the plunger spring S. R and S are housed in an extension J of the turret saddle.

The **first stage** in Fig. 22-2 shows the turret saddle in its forward operating position; the plunger R is seated in notch W, in plate X, and holds the turret rigidly in position. The **second stage** shows the turret saddle moving towards the right; the lug F on L has contacted the pin G in R, and has withdrawn R from notch W in plate X. The projecting pin Y is just contacting a tooth of the ratchet Q. In **stage 3,** the turret saddle has moved farther to the right and the turret has been rotated through an angle of about 45° by A. The turret saddle has moved back far enough so that lug F on cam L no longer contacts pin G in R, so the index locking plunger "rides" on the edge of plate X. In **stage 4,** the turret saddle has attained its extreme right position; the index plunger R has been forced by spring S into notch H. **Stage 5** shows the turret saddle moving to the left, or forward; springs M and U permit cam L and pawl A to "ride" over pin G and ratchet Q. The turret saddle advances to the left until the position illustrated in **stage 1** is again attained and the indexing cycle is complete. It should be noted that all turret machines and all machines that required indexing movements employ a similar mechanism, and while these devices may differ radically in design and construction from the one described, they all embody the two essential principles of this device, which are: an *indexing mechanism;* and a *device for locking the turret* after indexing is completed.

309. The turret T may be carried on a saddle as shown in Fig. 22-1 or on a ram moving within a dovetail slide on the turret lathe bed. **Ram-type machines** are used for light, high-speed work; **saddle-type machines** for large, heavier work of considerable length. Turret lathes for bar work have spindle noses fitted with spring collets similar to those illustrated in Fig. 11-9 and 11-10. Fig. 22-3 illustrates the principle of operation of a spring collet with a semi-automatic feeding device. The first stage shows the collet clamping the bar; the second stage shows the collet C advanced, releasing the bar. The feeding finger F is a split spring steel tube which grips the bar with a force considerably less than that exerted by the collet, but still sufficient to carry the bar forward when the collet is released as illustrated in stage 3. In stage 4, the feeding finger

has moved the bar to its farthest position, and the collet has moved to the left clamping the bar. The feeding finger is now returned to its original position in stage 1, but does not disturb the bar which is held by the collet. Both the collet and feed finger movements are controlled by levers on the

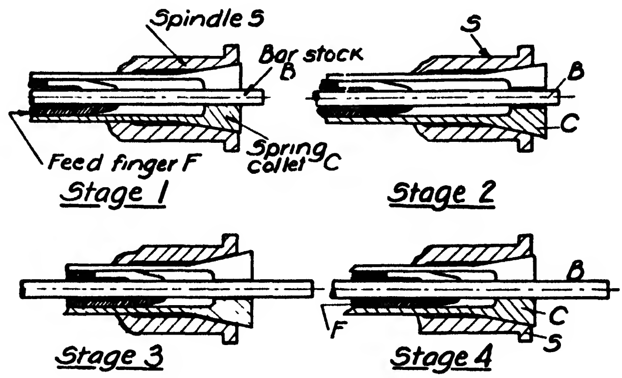
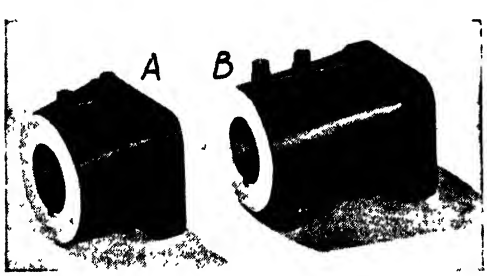


FIG. 22-3. Bar Chuck Operation.

headstock of the machine. The motion of the feed finger need not be particularly accurate, since the end of the bar generally makes contact with a suitable, properly set stop in the turret, and the feed finger then slides forward on the stock.

Outboard supports for bar stock are generally used on turret lathes, so that bars six feet or more in length may be used to eliminate frequent replacement by the operator. Several manufacturers supply a standard set of turret and cross-slide tools for bar work; the tooling arrangement is thereby semi-permanent so that change of work may require only a readjustment or a resetting of the tools used on a previous job. Such an arrangement facilitates production in that a great deal of setting-up time is eliminated.



Warner & Swasey Co.

FIG. 22-4. Flanged Tool Holders.

310. Turret lathe manufacturers list a great many **standard tools,** so that it is usually possible to set up a machine for any series of operations within its range without designing and constructing special equipment. **Fig. 22-4** shows two **flanged tool holders** which are bolted to the face

of the turret; the one at the left, *A*, is used for holding drills, and the one at the right, *B*, for reamers and boring bars. Fig. 22-5 shows how a drill is

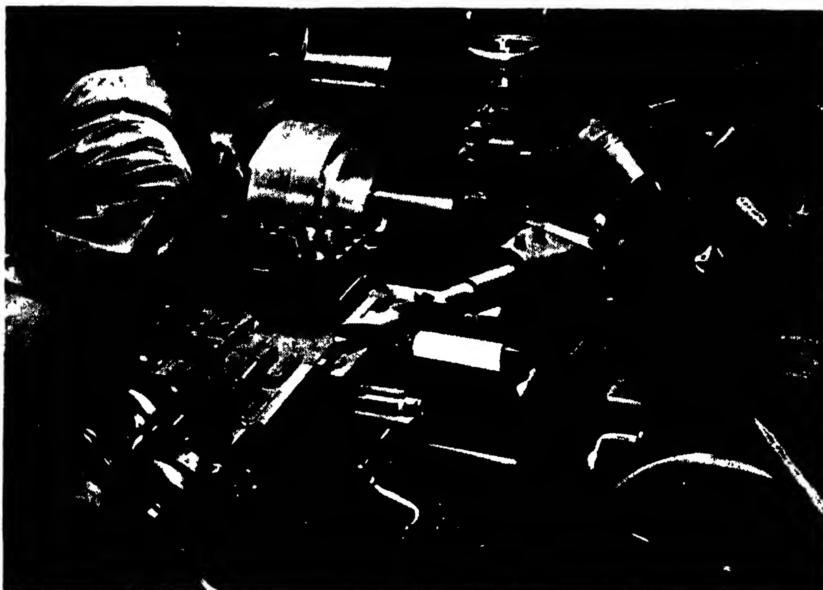


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FIG. 22-5. Turret Lathe Operation.

held in the shorter holder by using a bushing to adapt the drill shank to the holder hole. Fig. 22-6 shows a **boring bar** which fits into the holder

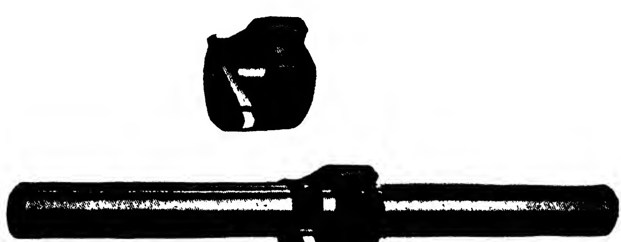

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FIG. 22-6. Piloted Boring Bar.

of Fig. 22-4 and has a grooved pilot at the front (left) end. The pilot fits in a bushing which is inserted in the nose of the machine spindle and turns with it. Fig. 22-6 also shows a separate cutter head for the bar.

Fig. 22-7 shows an **angular cutter stub boring bar** which may be held in the flanged tool holders of Fig. 22-4, or in other types of holders such as Fig. 22-9 and Fig. 22-11. This bar is used for rough and finish boring operations, and may be used for blind hole facing, since the cutting edge is positioned ahead of the end of the bar. Another type of **stub boring bar** has a cutter slot at each end at right angles to the bar axis. The slot at one end is open so that flat or double-edge cutters may be employed for counterboring or facing operations. A closed-end slot at the other end of the bar is used for boring, recessing, and back-facing.

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Fig. 22-7. Angular Cutter Stub Boring Bar.

Fig. 22-8 shows an **adjustable knee tool** for simultaneous turning, boring, drilling or centering operations. The shank of the tool is held in an adapter plate which is bolted to the face of the turret. The shank and body of the tool are hollow so that drills or boring bars may be held by using adapter bushings. The turning tool is carried in a slide, and is adjusted for diameter by turning the graduated screw. The knee tool is used for quick set-ups on short bar work but can also be used for machining small castings.

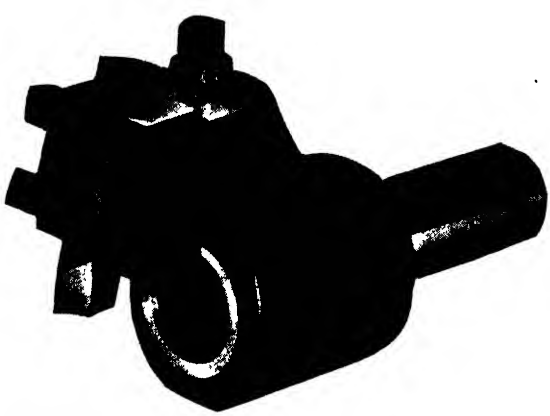

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Fig. 22-8. Adjustable Knee Tool.

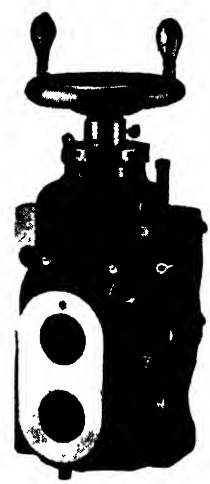

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Fig. 22-9. Slide Tool.

The **slide tool** is probably the most important turret lathe tool for small and medium lot production. It has a vertical base which is bolted to the turret face, and which carries a slide which may be moved and adjusted by a screw rotated by the handwheel at the top. The slide is equipped with two adjustable stop screws to limit its travel during recessing and back facing operations; the slide may be clamped to the base for boring cuts. The slide has two holes; the lower hole may be aligned with the center line of the spindle and used for drills, reamers, or boring bars; and the upper hole may be used for a turning tool holder like that illustrated in Fig. 22-10. The slide tool is used for blind recessing

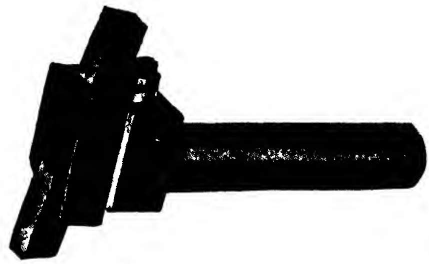

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FIG. 22-10. Adjustable Angle Cutter Holder.

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FIG. 22-11. Adjustable Single Turning Head.

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FIG. 22-12. Combination End Facing and Turning Tool.

in conjunction with the stub boring bar previously described; the bar is positioned in the work and the slide is then moved up to turn the recess.

Fig. 22-10 shows an **adjustable holder** for turning and facing **operations.** The tool bit is clamped in a slide which may be adjusted in the body of the tool by the graduated screw. Plain straight and angle cutter holders, without the adjustable slide, are also extensively used.

Fig. 22-11 shows an **adjustable turning head** for combined turning and boring cuts. The lower hole is used for holding a drill or boring bar, while the adjustable slide carries a plain or an adjustable cutter holder like Fig. 22-10. The slide may be positioned by using the pointer and scale, and the large dial provides the final accurate adjustment for size. The central hole, at the left, in the body of the tool may be used for a second turning tool holder for such operations as facing in which a limited radial adjustment is required. The large hole at the top of the tool body affords clearance for the overhead pilot bar shown in Fig. 22-1; a suitable flanged bushing is bolted to the turning head and slides on the pilot bar, thereby increasing the rigidity of the turning head by uniting the tool with the headstock of the machine.

The combination **turning and facing tool** shown in Fig. 22-12 is held in an adapter bolted to the turret face and is used for two types of work. Using a square cutter, as illustrated, it serves as a single cutter turning tool; with a flat cutter it becomes an end facing tool. The holder carries two adjustable rolls which serve as a follower rest and support the work while the cutter operates. The tool can be used as a steadyrest for heavy cross slide cutting operations by removing the adjustable cutter block. The tool can also be used for chamfering, forming, or facing the ends of shafts or bars by using a flat cutter ground to the proper shape.

Fig. 22-13 shows a combination **center and stock stop** which may be held in a flanged tool holder, Fig. 22-4. With the center retracted, it serves as a stop while the stock is advanced. The center may be advanced, as illustrated, to support the outer end of long work during cross slide operations. A similar tool embodies a stock stop with a starting or spotting drill instead of the center. These tools are used when it is necessary to reserve five turret faces for succeeding operations.

311. The four-sided cross-slide turret is used for holding **forged tools** and stellite or tungsten-carbide **tipped tools** for turning, facing, and cutting-off operations. Fig. 22-14 shows several high-speed steel forged cutters. *X* represents a combination **cut-off and chamfering cutter,** which is used from the rear of the spindle; *B* is a straight right-hand round nose **turning cutter**; *D* is a right-hand bent round nose **turning cutter**; *H* is a **square-nose cutter**; and *T* is a right-hand bent **facing cutter.**

Fig. 22-5 shows how these cutters are held in the square turret by set screws. Adjustment for cutter height is obtained by a wedge or rocker, similar to that used in an engine lathe tool post, bearing on the curved

surface of the turret base. Cutters may also be held in single cutter tool posts similar to engine lathe tool posts, with the exception that a pair of opposed wedges are used for cutter height adjustment instead of the conventional dished ring and rocker.

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FIG. 22-13. Combination Stock Stop and Center.

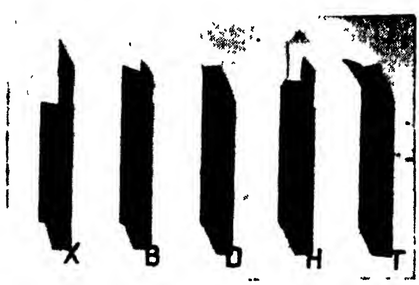

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FIG. 22-14. High-speed Steel Forged Cutters.

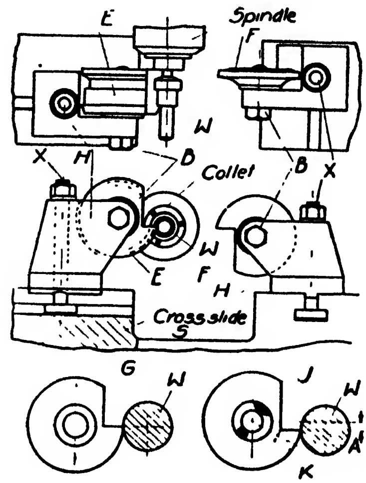

FIG. 22-15. Circular Form Tool Application.

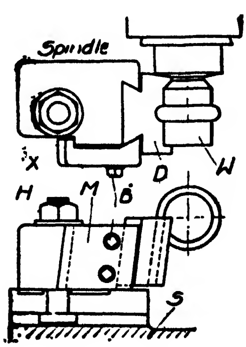

FIG. 22-16. Straight Form Tool Application.

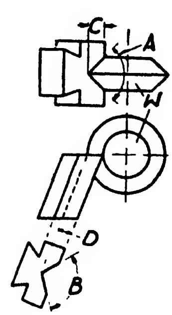

FIG. 22-17. Form Tool Profile and Section Contrast.

312. Straight and circular forming cutters are used for form turning and special profiles and can be ground without changing their shape. Fig. 22-15 illustrates the application of front and rear **circular form tools** *E* and *F* on the cross-slide. Both cutters are held by clamping

screws *B* in tool holders *H*; in most instances an auxiliary clamp is used to adjust the cutter to height and to give additional clamping effect. In the illustration, the front cutter is used for forming a shoulder screw blank, and the rear cutter for forming the top of the screw head and for cutting off the

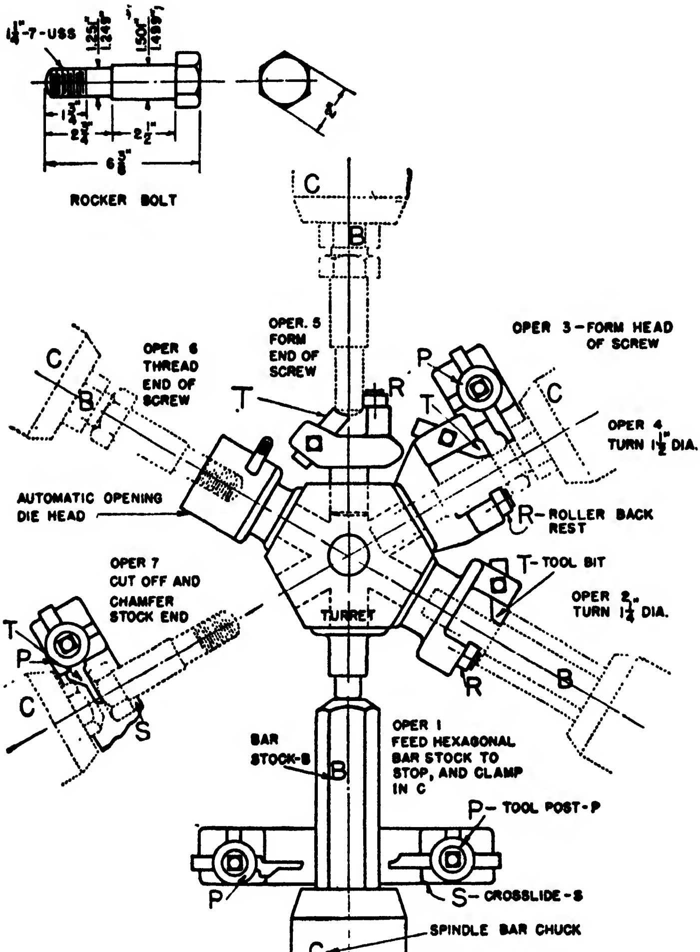

FIG. 22-18. Turning Rocker Bolts on a Turret Lathe.

finished part. The holders *H* are keyed to the tee-slots in the cross-slide *S* and are clamped in place by tee-bolts *X*.

The **cutting face** of a circular form cutter is **ground** along a line **parallel** to and a distance *A* from a radial center line, in order to provide

clearance for the cutting action and avoid the insufficient clearance indicated in the radially-faced cutter *G*, Fig. 22-15. The center of the cutter *J* must therefore be set a distance *W* above the centerline of the spindle. The dotted line at *K* illustrates correct regrinding procedure.

Fig. 22-16 shows a **straight form cutter** *D*, which is held in a holder *H* by a dovetail and a clamp *M*. The clamp is fastened by two screws *B*. Cutters of this type are inclined to the vertical in order to provide cutting clearance, and are ground on the top face only, so that the cutter contour will be unaffected by sharpening.

Fig. 22-17 shows how the clearance inclination affects the actual section of the straight form tool. In this illustration the top view shows the required cutting profile with a depth *C* and an included angle *A*. The section of the cutter, however, as shown by the auxiliary view, actually has a depth *D* and an included angle *B*. In an inclined cutter or in an offset circular form tool as at *J*, Fig. 22-15, it is therefore evident that the actual section of the tool differs from the profile of the work.

313. Fig. 22-18 shows a turret lathe tooled for **turning rocker bolts from hexagonal bar stock.** The rocker bolt is shown at the top of the figure, and the spindle and work are represented at each station as though the spindle were indexed around the turret. Operation 3, a cross slide, and operation 4, a turret operation, are performed simultaneously. A self-opening die head similar to that shown in Fig. 16-28 is used in operation 6. Plain tool posts with single forged tools are used on the front and rear seats of the cross slide.

314. Fig. 22-19 shows a machine, and Fig. 22-20 the tool layout for the **production of steel roller end plugs** for lawn mowers. The plugs are made from 2½" diameter **bar stock** in two minutes each, floor to floor time. The stock is held in a collet chuck and advanced to a stock stop. The ⅝" hole *A* is drilled and reamed by the next two turret stations to a tolerance of plus or minus .001". At the same time the roller hub *C* is turned with a forming tool held in the square turret. The bore is chamfered and the face *B* machined by the next two turret stations, while the surface *D* is faced by the cross slide turret tool. The final forming and cutting-off operation is performed by a tool held in the rear cross slide tool post while the idle turret face is opposite the spindle.

315. Fig. 22-24 shows a forging and a machined steel ratchet wheel for a coal stoker. This wheel was originally made in two parts, a notched steel rim was pressed on a cast iron hub and pinned in place; a bronze bushing was then pressed in the hub and the entire assembly taken to a lathe for sizing the bushing bore. This method required lathe, press, drill press and bench work. A steel forging was substituted for the two original

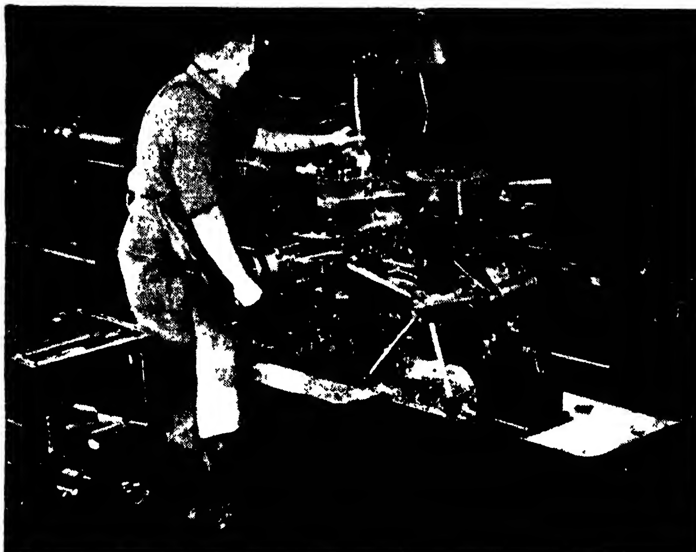

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FIG. 22-19. Machining Roller End Plugs on a Turret Lathe.

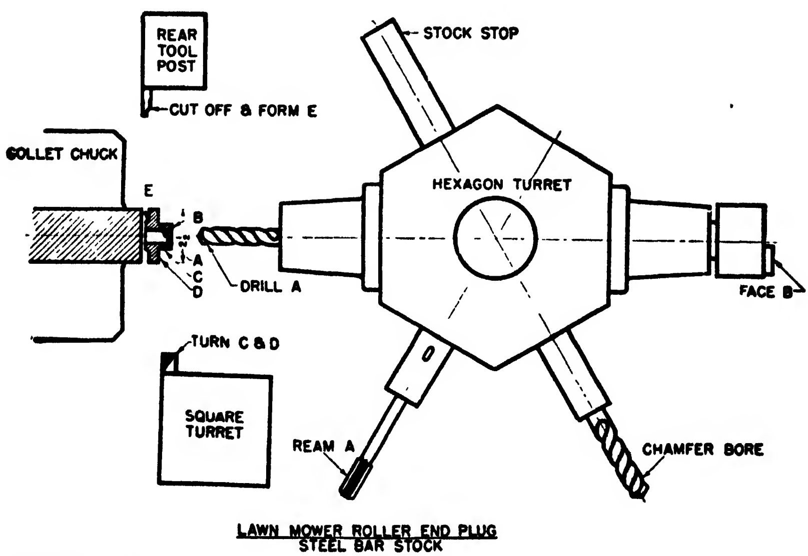

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FIG. 22-20. Tool Layout for Machining Roller End Plugs.

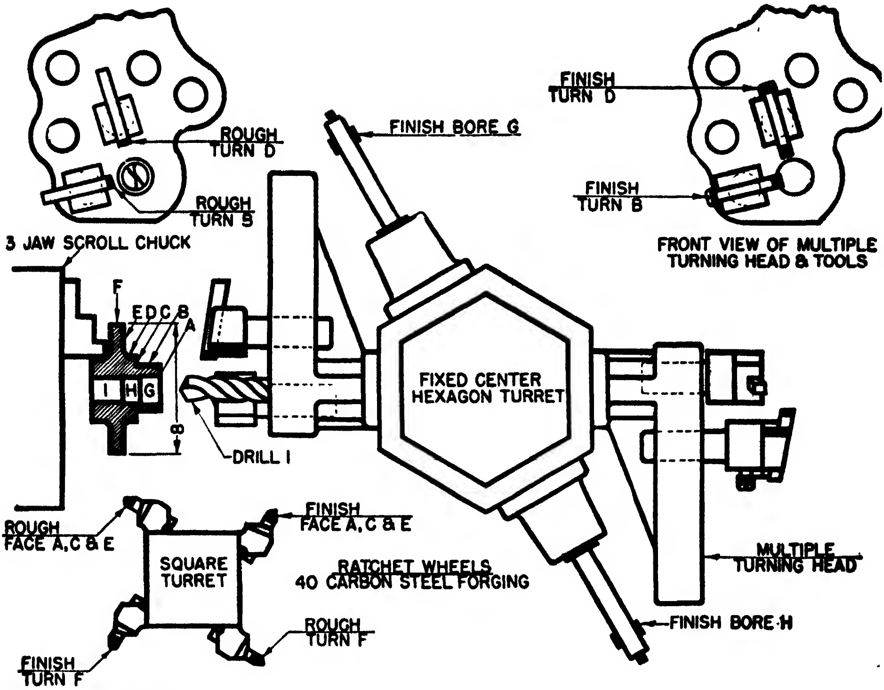

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FIG. 22-21. Tool Layout for Ratchet Wheels, First Series of Operations.

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FIG. 22-22. Machining Ratchet Wheels on a Turret Lathe, First Series of Operations

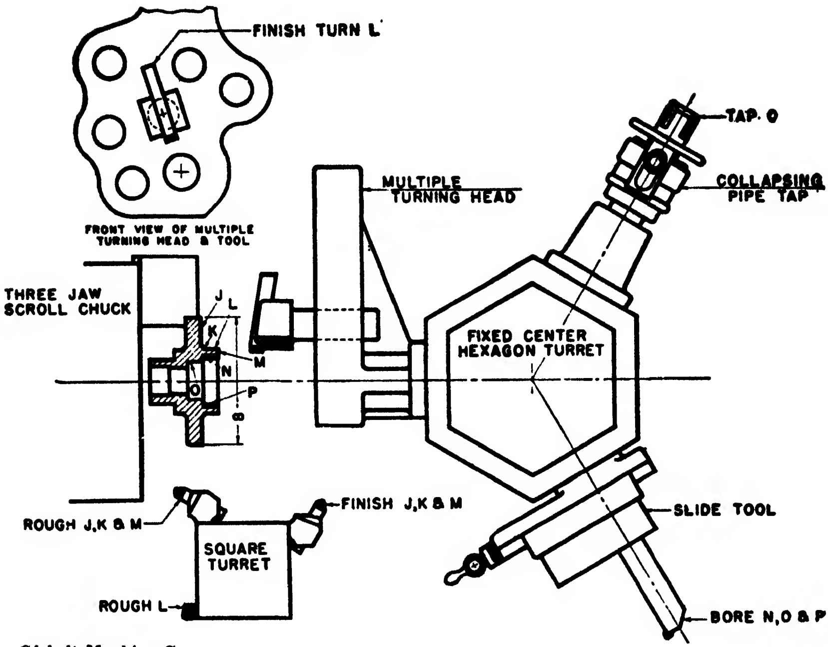

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FIG. 22-23. Tool Layout for Ratchet Wheels, Second Series of Operations.

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FIG. 22-24. Forging and Finished Ratchet Wheel.

parts, and machined in two separate chucking operations in a turret lathe in eighty minutes for the 8″ wheel shown. The turret lathe used for these operations has overhead pilot bars that slide in a guide bushing on the headstock and are carried in the tool holders.

In the **first series of operations,** the forgings are chucked on the rear hub with hard jaws in a three jaw chuck. In the second series of operations they are chucked on the finished outer diameter with soft jaws. In the first series of operations, Fig. 22-21, surfaces *A, C,* and *E* are rough-faced by a cross-slide tool; hole *I* is drilled and surfaces *B* and *D* are rough-turned by tools held in a multiple turning head, while *F* is rough-turned by a cross slide turret tool. *G* is then finish-bored with a two-lipped boring bar. The finishing operations are performed in a similar manner and the part is completed by finishing-boring *H*. In the **second series of operations,** Fig. 22-23, surfaces *J, K,* and *M* are rough-faced, *L* is rough-turned, and *J, K,* and *M* are finish-faced with the cross slide turret tools. Surface *L* is finish-turned with the angle cutter holder in the multiple turning head in the hexagonal turret, and surfaces *N* and *O* are bored by an angular cutter boring bar held in a slide tool. The bronze bushing is then pressed into the seat formed by surface *N,* and the bore *P* of the bushing is bored by the same bar. The threaded hole is then tapped with a collapsing pipe tap.

316. Fig. 22-27 shows a semi-steel casting before and after machining on a turret lathe. These castings are handled in production lots of 200 and each part is held in a 24″ four-jaw independent chuck by means of a *bonnet* bolted to the face of the chuck. Nine tungsten-carbide tools and one high-speed steel tool are used in the machining process which requires 40 minutes. The part is rough-faced from the square turret tool post while the tapered hole is simultaneously rough step-bored with a series of single-point tungsten-carbide cutters set in a piloted boring bar. The hole is then rough counterbored, semi-finish and finish taper-reamed with piloted taper reamers, finish-counterbored at *B* and *C,* and chamfered and finished at *E* and *F*.

317. Many types of work are more conveniently handled on **vertical turret lathes** than on horizontal-spindle machines. A modern vertical turret lathe is illustrated in Fig. 22-28. The table is horizontal, which facilitates handling and clamping heavy or odd-shaped work, and is equipped with four independent chuck jaws. The turret is carried on a vertical slide which moves in a saddle supported by the cross rail. The saddle moves horizontally and the turret slide vertically; both motions may be power-actuated, and include both feeding and quick traverse, the latter for setting-up purposes and for approaching the work and returning after a cut. The

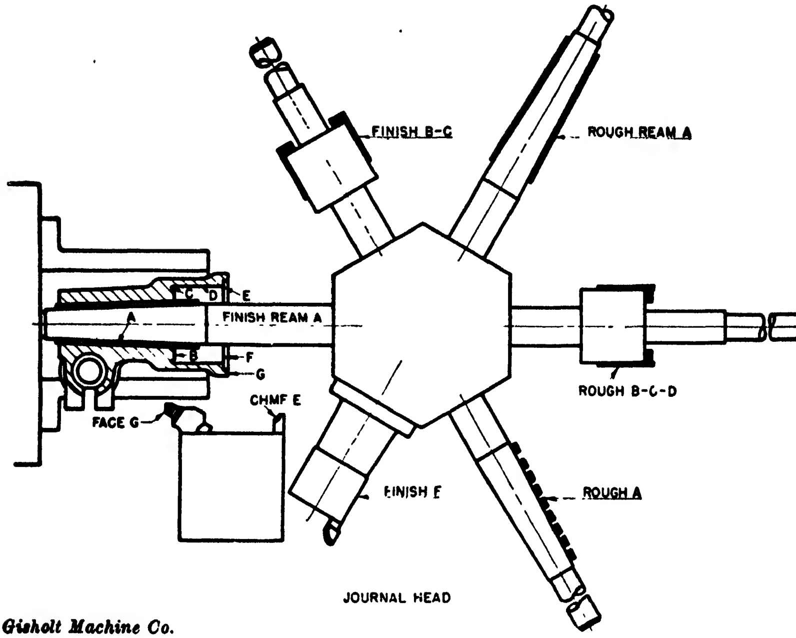

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FIG. 22-25. Tool Layout for Machining Journal Head.

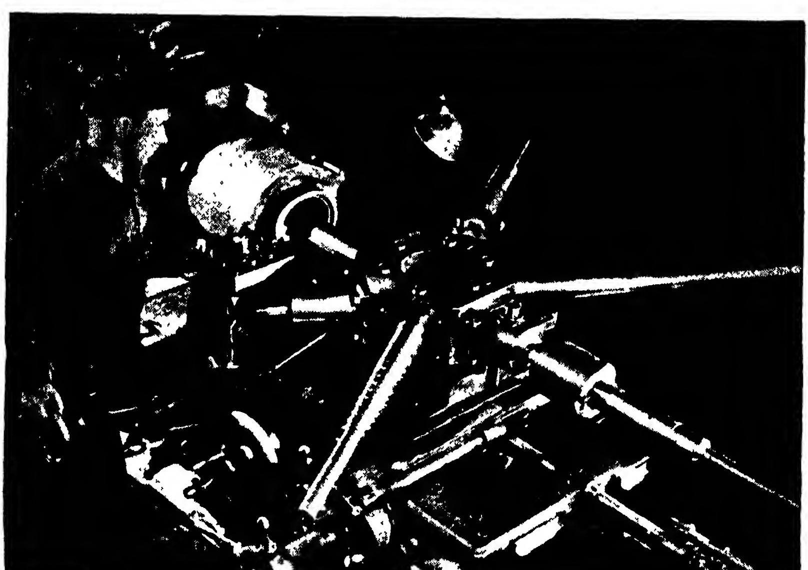

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FIG. 22-26. Machining a Journal Head on a Turret Lathe.

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FIG. 22-27. Pulverizing Machine Journal Head Semi-steel Casting—and Machined Part

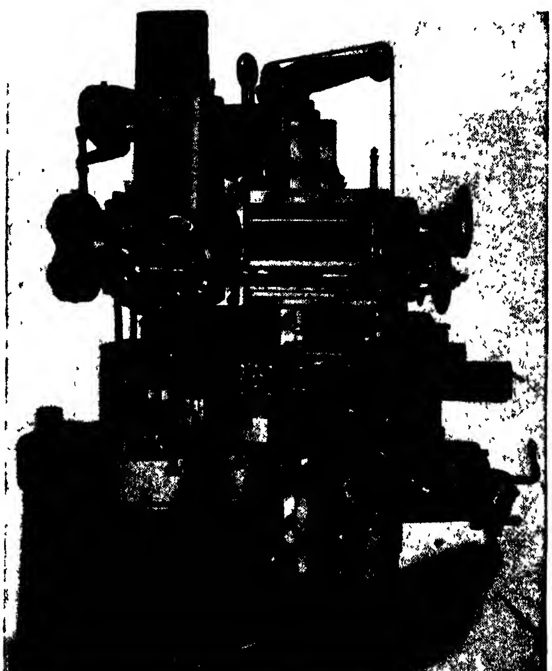

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FIG. 22-28. Vertical Turret Lathe.

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FIG. 22-29. 64" Vertical Turret Lathe with Auxiliary Ram.

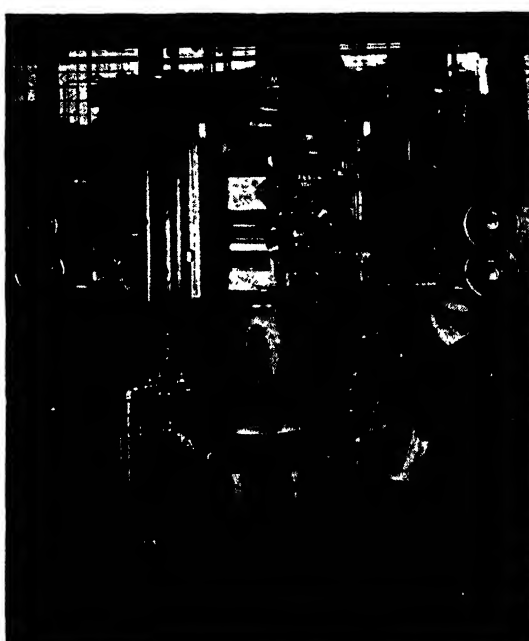

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FIG. 22-30. 42" Vertical Turret Lathe with Auxiliary Ram

side head shown at the right carries a square turret which corresponds to the cross slide turret of a horizontal lathe, and has power-actuated feed and quick traverse motions in horizontal and vertical directions. Another machine shown in Fig. 22-29 has an auxiliary ram on the cross-rail, which serves as an additional cutting head when required. The ram has vertical and horizontal power-actuated feed and quick traverse motions.

Fig. 22-29 shows three simultaneous cuts on a large casting. The ram head is used for boring, one station of the turret is used for a facing operation, and the side head is used for turning the periphery of the casting.

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FIG. 22-31. Duomatic Lathe.

Fig. 22-30 shows the turret and the side head cutters operating on a part that would be very difficult to hold on any machine other than a vertical turret lathe.

318. Automatic and semi-automatic turning and facing machines are used for such a variety of parts, and operate on so many diverse principles that only a few representative types of machines can be considered in this section. In the manufacture of parts on semi-automatic turning equipment, the work may be held between centers or in a standard or special chuck and both single and multiple-spindle machines are used.

319. Fig. 22-31 shows a **semi-automatic lathe** which resembles a geared-head engine lathe in principle but is provided with two independent front and rear carriages. Each carriage supports a tool slide which may move perpendicular to the spindle of the machine. Power-actuated feed and rapid-traverse forward and return motions are available for each carriage and for the tool slides. Both carriages can be used simultaneously

for turning or for facing, or one may be used for turning and the other for facing. Feed screws provide a longitudinal movement for each carriage and also drive the cross feed screws of the tool slides. An adjustable micrometer sleeve arrests the movement of the tool slide and fixes the diameter of the work. The longitudinal movement of the carriage may be limited by adjusting a pair of lock nuts on the threaded stop bar.

Fig. 22-32 illustrates how the **grooves of two vee-belt sheaves** 7¾″ in diameter are machined on this lathe. The sheaves are held on a special *nut-mandrel* supported in the spindle and rotated by a driving pin on the face plate of the machine. The other end of the mandrel is supported by the tailstock center. The front tool slide carries four roughing tools, and the rear tool slide four inverted finishing tools backed up by a special upper support. The spindle speed is 37 r.p.m., and the feed rate for both operations is .011″ per revolution. The carriage remains stationary, and the front slide advances to the rear, feeds, and returns to the front. The rear tool slide then advances to the front, feeds, and returns to its original position at the rear.

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FIG. 22-32. Grooving Vee-belt Sheaves on a Semi-Automatic Lathe.

Fig. 22-33 shows a series of rough and finish turning and forming operations on a 6″ diameter 21″ long **projectile.** The part is rough-turned at a speed of 37 r.p.m.; the three tools on the rear carriage have a feed of .014″ per revolution and are used for roughing the cylindrical portion of the shell; the single tool in front is used to rough-form the nose of the shell. This tool is mounted on a special tool slide that is guided traversely by a grooved cam plate attached to the machine bed. Finish-turning and forming are accomplished by the same set of tools using a feed of .018″ for the rear, and .029″ for the front set of tools at a speed of 50 r.p.m. The work is held on an air-operated expanding arbor chuck in the spindle and supported by the tailstock center.

320. Fig. 22-34 shows a **cam-controlled semi-automatic lathe** which has front and rear tool carriages or slides mounted on horizontal cylindrical

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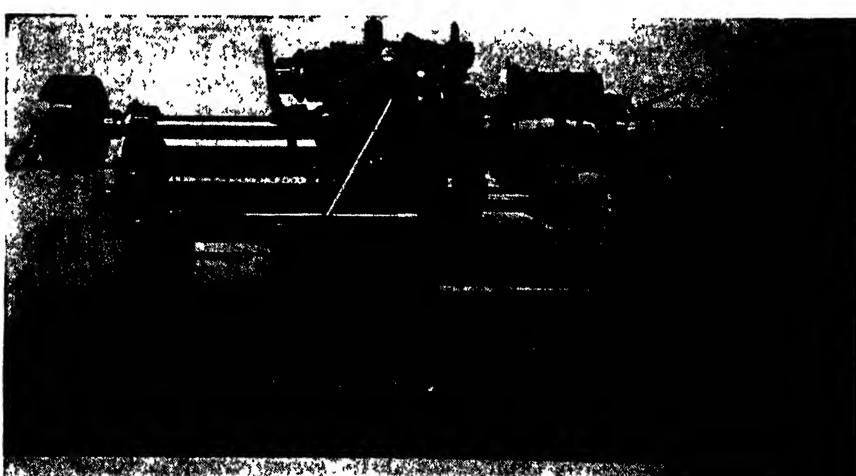
FIG. 22-33. Shell Turning on a Semi-automatic Lathe.

bars. The bar in front, on which the front carriages are mounted, is moved longitudinally by a cam on the master drum at the left, and thereby operates



Jones & Lamson Machine Co.

FIG. 22-34. Fay Automatic Lathe.

the tools for turning operations. The carriages may be tilted or oscillated about the axis of the supporting bar while feeding longitudinally, by the

cams on the front of the bed for taper turning or forming operations. Similar carriages are supported on another bar at the rear. This machine is shown turning and facing tool joints for oil-well casings. The forging and the completely machined part are shown on the floor at the right in Fig. 22-34.

Jones & Lamson Machine Co.

Fig. 22-35. Lathe with Center Drive Attachment.

Fig. 22-35 shows a shaft 32″ long and 1¾″ in diameter supported on centers and driven by a center drive attachment which has a three-jaw eccentric drive fixture, detailed in Fig. 22-36. The shaft is delivered to the lathe milled to length with both ends centered. The front carriage at the

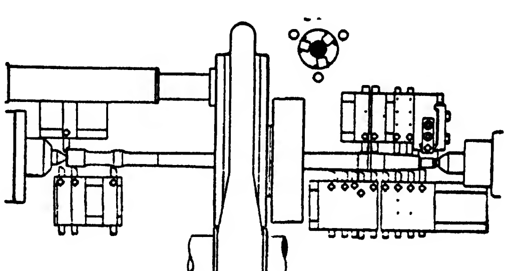


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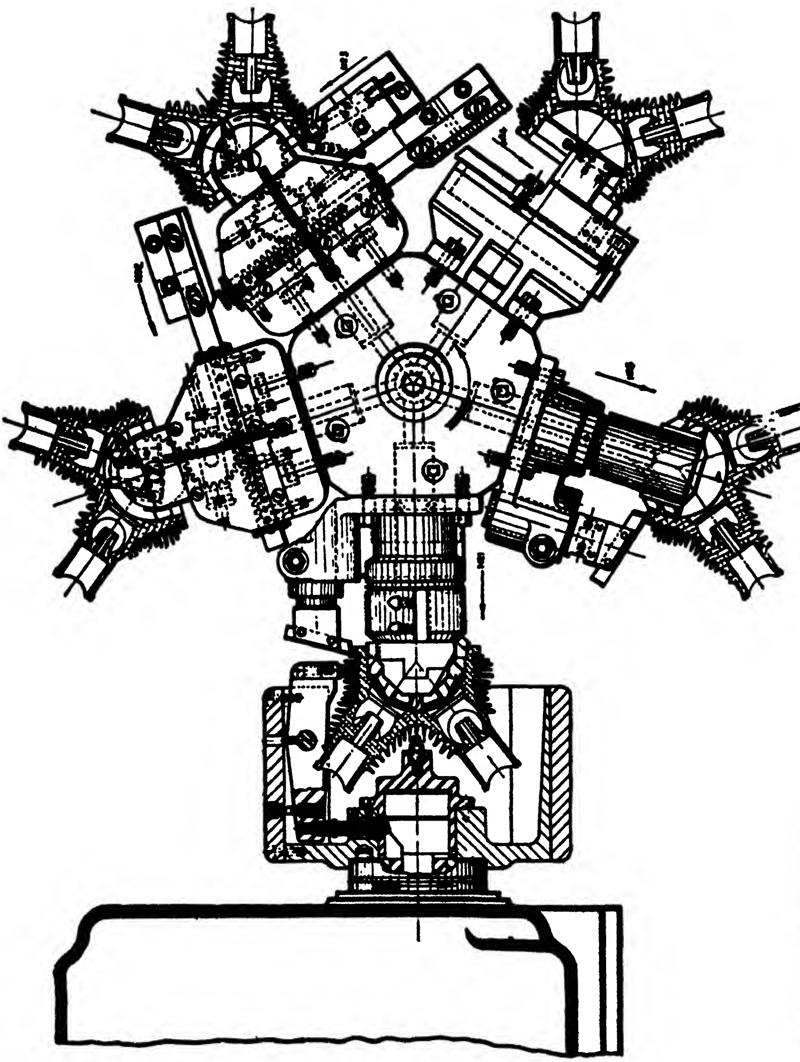
Fig. 22-36. Tooling Diagram for Shaft Turning on Fay Lathe.

extreme left carries three tools for turning, and the back arm carries a chamfering tool. At the right end, a front carriage with five tools turns the straight diameters, and another carriage with four tools turns the taper and rough-turns the thread diameter. The back arm with five tools finish-



Potter & Johnston Machine Co.

FIG. 22-37. Tooling Layout for Machining a Cylinder Head.

forms the thread diameter, and forms all shoulder lengths, necks and chamfers. The production rate is 44 shafts per hour ready for grinding.

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FIG. 22-38. Machining a Cylinder Head—Front View of Chucking Machine.

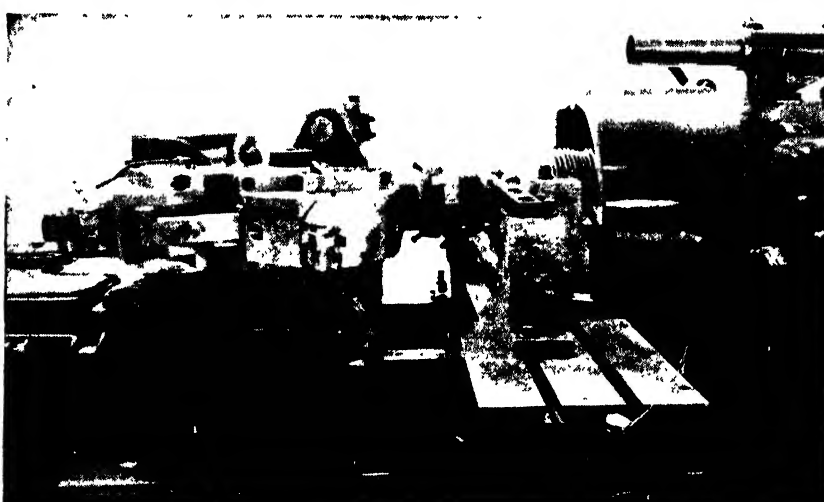

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FIG. 22-39. Machining a Cylinder Head—Rear View of Chucking Machine.

321. Automatic turret lathes and chucking machines are essentially horizontal-spindle turret lathes, with all controls mechanically or hydraulically actuated so that all the operator does is to load and unload the work,

and resharpen and reset tools when required. A modern **chucking machine** is illustrated in operation in Fig. 22-38 and 22-39. A five-station turret is mounted on a turret saddle whose motion is controlled by cams bolted on a cylindrical drum underneath. A second cam drum, placed beneath the cross slide perpendicular to the ways of the machine, controls the motion of the cross slide. Single or multiple non-indexing tool holders may be mounted on the front and rear cross-slide stations.

Fig. 22-40 shows an aluminum alloy **cylinder head** for an airplane motor, in which the several cylindrical surfaces, and the spherical surface of the combustion chamber are finished on a chucking machine. The part is held in a fixture mounted on the spindle of the machine, and is located and rapidly centered by a pin in the spindle nose that fits a hole drilled in the part. The work is gripped by three air-operated jaws that bear on the outer diameter of three previously-finished fins. The cross-slide is used to actuate the turning tool holders in the second and third turret stations so that the combustion chamber surface can be accurately generated. The cross slide is also used to actuate the recessing tool holder at the fourth turret station. One operator can handle two machines with a total production of 13 finished parts per hour.

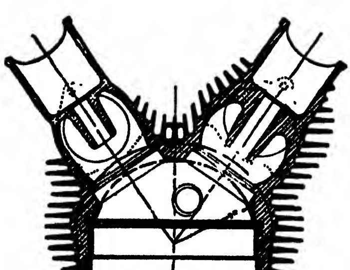

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Fig. 22-40. Cylinder Head.

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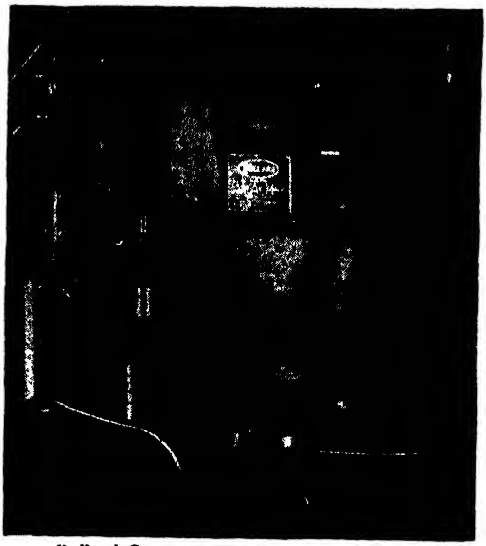
Fig. 22-41. Vertical Automatic Lathe.

Fig. 22-41 illustrates the Bullard Multi-Au-Matic, which is **essentially a vertical automatic lathe** with from four to eight vertical work spindles, and from three to seven tool heads. The tool heads are above the work spindles and remain in a stationary position on the central column, except for their necessary functional movements. The work spindles are carried in a heavy turret which revolves about the central column at its base and indexes the spindles under each successive tool head. Each spindle is automatically given its proper rotary speed for the work done at each station. The spindles are stationary at the loading station and during indexing.



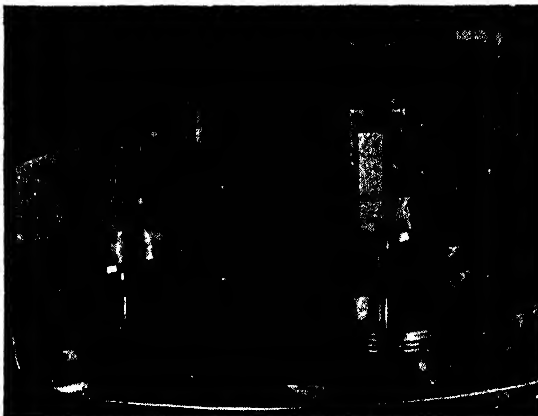
...e Bullard Co.

FIG. 22-42. Machining a Cast Iron Flange on the Multi-Au-Matic.

The tool-carrying heads are mounted on the faces of the central columns at the various work stations. Each head has independent motion. Standard heads have one movement either vertical, angular or horizontal, but double-purpose heads with two slides for vertical and horizontal movement can be attached.

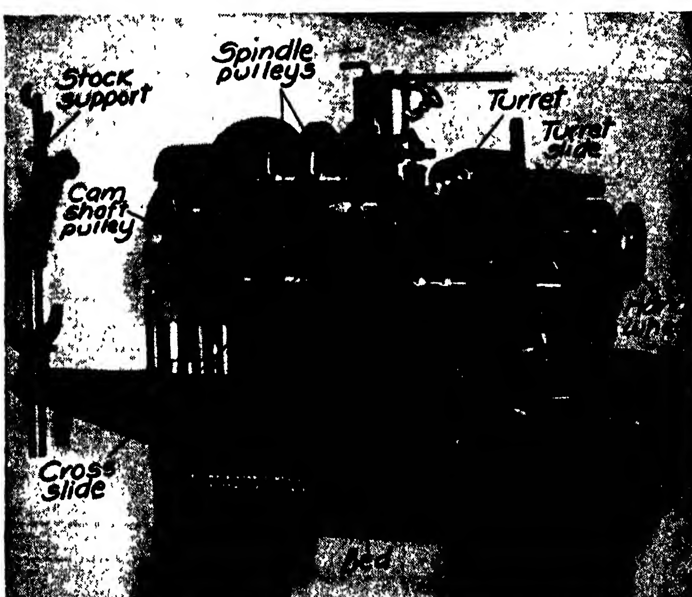
Fig. 22-41 shows an eight-spindle machine with seven tool stations; one station is blank and is used for loading and unloading the work. One completed part is produced every time the turret indexes, and the longest operation at any station therefore determines the production rate. The Multi-Au-Matic method of production involves dividing the machining process on a given part into operations and work units such that the processing time on all or most spindles is the same; for example, if a given part requires facing, drilling and boring operations that take one minute each, and a turning operation that takes two minutes, the turning operation would probably be performed at two adjacent stations in two stages of one minute each.

The Bullard Contin-U-Matic is a six- or twelve-station **automatic vertical lathe,** in which six or twelve vertical work spindles and six or twelve tool carrying units are automatically indexed about a central column. The machine is designed for boring, turning and facing operations of various types, singly or in combination, and primarily assumes that



The Bullard Co.

FIG. 22-43. Six-station Contin-U-Matic.



Brown & Sharpe Mfg. Co

FIG. 22-44. High-speed Automatic Screw Machine.

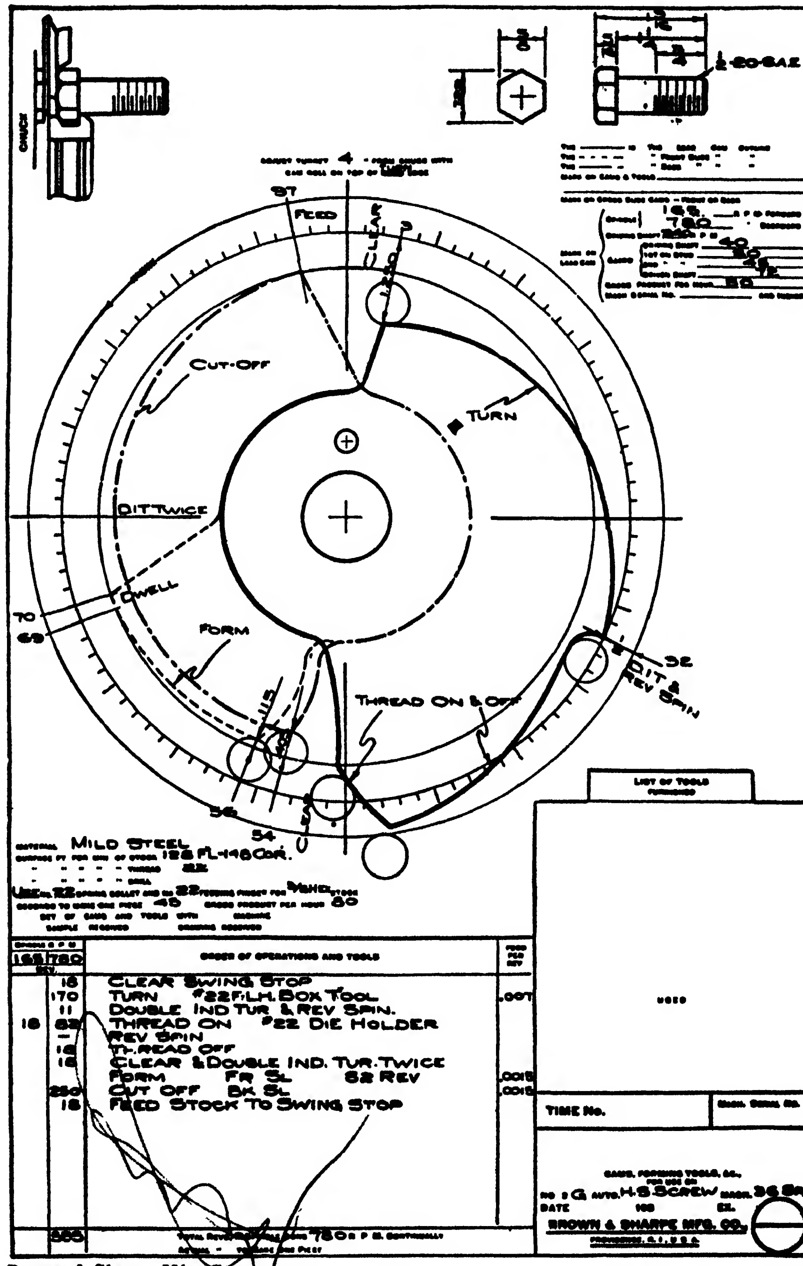


FIG. 22-45. Cam Design Sheet.

identical operations are to be performed at each of the respective work spindle and tool head stations. Means are provided for chucking the work while each unit passes through the loading sector. The work spindles do not rotate while loading, and the tool heads are stationary at their highest position. In the complete cycle of the machine, six or twelve pieces of work are in process at one time, and the total elapsed time for one finished part is therefore one-sixth or one-twelfth of the complete cycle of the turret.

322. Automatic screw machines are essentially full-automatic bar stock turret lathes. There are two important types: single-spindle and multiple-spindle machines. Fig. 22-44 shows a **single-spindle** high speed automatic screw machine for producing screws and other parts from bar stock ⅜" or less in diameter. The work spindle is driven by open and

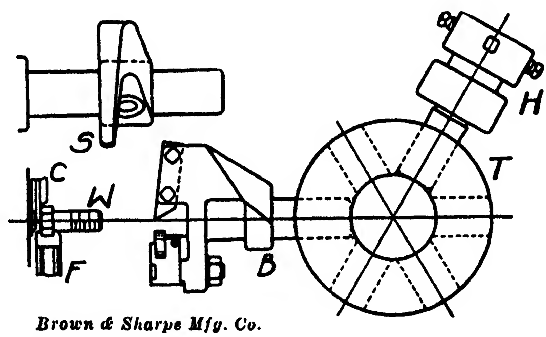


FIG. 22-46. Tool Layout for Hexagonal Head Screw.

crossed belts so that the spindle rotation may be reversed for threading operations. The turret rotates on a horizontal axis in a plane parallel to or coincident with the spindle axis, and has six tool stations. There are two cross slides, front and rear, and both cross slides and the turret slide are actuated by disc or plate cams shown in Fig. 22-45.

The bar stock is held in a collet chuck, and is advanced by a feed finger similar to the mechanism illustrated in Fig. 22-3, to a stop held in the turret or on a swinging arm, Fig. 22-46. Drills, reamers, threading and knurling tools are carried in the turret: form and cut-off tools are carried on the cross slides; but some turning tools such as knee tools and hollow mills are held in the turret and are used for heavy cuts, since end cutting imposes less strain on the work and the machine than side cutting. Side cutting and forming is generally performed with circular form tools illustrated in Fig. 22-15, although straight form tools are also used.

323. End cutting rough turning tools are of two general types: the **hollow mill** shown in Fig. 22-47, and **knee tools** similar to the one shown in Fig. 22-8. Knee tools for automatic screw machines are generally made without an adjusting slide; the tool bit is held by two or three set screws in the solid body of the tool. Knee tools are used chiefly for taking roughing cuts on short work which is finished by a circular forming tool. Hollow mills are made in the plain or non-adjustable type illustrated, but are also constructed with a body holding two adjustable inserted blades, 90° apart, and two inserted back rests which can be adjusted independently.

Box tools are used more generally than any other type for turning straight diameters and are designed primarily for finish turning. The tools have blades which cut tangentially as illustrated in Fig. 22-48, and are equipped with vee back rests as illustrated, or with roller back rests as in the tool shown in Fig. 22-12. **Roller rest** tools are preferred for heavy cuts when a diameter is to be turned in one cut; **vee rest** tools are used for finishing cuts or on free-cutting material such as brass. Box tools with several cutters for turning two or three diameters simultaneously are also employed.

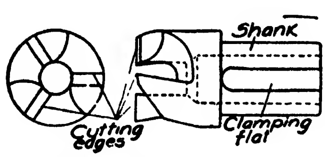


FIG. 22-47. Plain Hollow Mill.

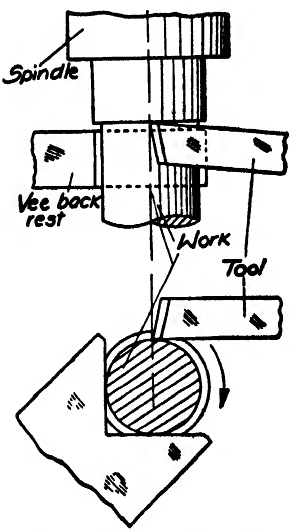


FIG. 22-48. Box Tool Application.

Tap holders and die holders are made in two styles: plain draw-out type, in which the holder is sufficiently free axially in the body to permit the tap or die to lead itself after being started; and releasing type holders similar to Fig. 16-27.

324. Fig. 22-46 shows a **tool layout for machining a hexagon head screw** on a machine similar to the automatic of Fig. 22-44. In this illustration, in which the *front* elevation of the turret and the *plan* of the cross slide is shown, *T* represents the turret, *H* a die holder, *B* a box tool for turning the body of the screw, *F* a circular form tool for facing and forming the head, *C* a circular cut-off tool, and *S* the swinging stop. The cam layout for this set of operations is illustrated in Fig. 22-45; the *heavy*

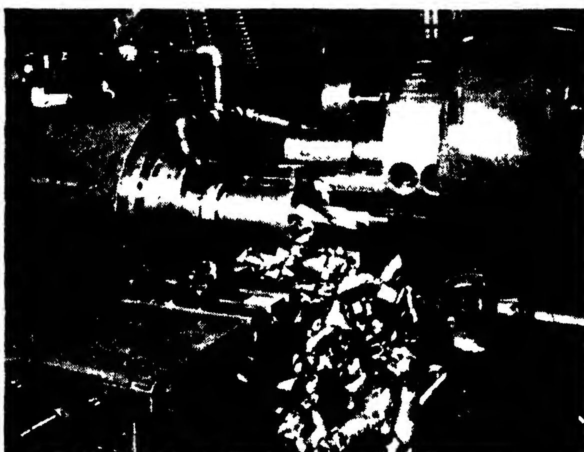
line represents the turret slide cam, the *broken* line the cam that actuates the front cross slide and the circular form tool, and the *dot-and-dash* line the cam that actuates the rear cross slide and the circular cut-off tool.

In operation, the hexagonal bar stock is brought against the stop S which has been swung into position; the stop is swung clear, and the screw body is turned with the box tool. During this period the spindle is rotating in a clockwise or backward direction at 780 r.p.m. The spindle rotation is reversed so that it runs forward at 165 r.p.m.; during this time the turret has indexed to bring the die in the holder H to the work. The screw body is threaded and the spindle is again reversed to 780 r.p.m. backwards, permitting the die to be withdrawn at a rapid rate. The turret slide then moves farther back and indexes to present a blank hole to the work. The circular form tool on the front slide forms the head and moves away from the work, and the rear form tool cuts off the screw, completing the cycle of operations.

325. Small **fillister and oval head screws** may be made from **round stock** by using a stock stop, a left hand drill, and a die holder in the turret, and a single form tool for both forming and cut-off operations on the rear cross slide. The form tool cuts off a previously finished screw and turns the body for a fresh blank while the spindle rotates at high speed in a clockwise or backward direction; the left hand drill in the turret is then advanced and fed a short distance to remove the burr left by the cut-off operation and to cut a very shallow conical spot in the end of the screw body. The turret then indexes to the die station while the spindle reverses its rotation, and the screw body is threaded at a slow forward speed. At the conclusion of the threading operation, the spindle again reverses and the die is backed off. The turret indexes to the station which holds the stock stop, and the stock is advanced against it. The turret then indexes to a blank station, and the form tool is brought forward to cut off the finished screw and form the body for the next screw.

326. A **screw slotting attachment** is easily applied to this machine. The attachment consists of a circular slotting saw which is driven by a round belt; a swinging arm which is actuated by a standard cam is swung down to pick up the finished screw as it is cut off. The arm presents the screw to the slotting saw, and holds the screw while the head is slotted. The arm then backs away from the saw and the finished screw is ejected and drops into a work chute. Since the slotting operation takes place while the next screw is in process, the production rate of the machine is not affected by this operation, which eliminates a separate slotting operation. Light milling operations can also be accomplished with this attachment. A **cross-drilling attachment** for drilling radial holes in the work while the machine is completing the next part is also available.

327. The Brown and Sharpe automatic screw machine is adapted to **high-speed, very accurate work,** but requires relatively expensive tools for a new job. In the manufacture of the hexagonal screw previously described, front and rear circular form tools and three plate cams are required. In the manufacture of the fillister head screw, a rear circular form tool and two plate cams are required, one for the turret slide and the other for the rear cross slide. (The stops, drill and die holders, box tool, and slotting attachment cam are all standard equipment and may be repeatedly used.) The high spindle speeds that may be obtained on this machine, however, permit the **substitution of brass for the usual cold-finished steel screw stock,** in order to take advantage of the



Cleveland Automatic Machine Co.

Fig. 22-49. Single Spindle Automatic Screw Machine.

much higher cutting speeds permissible with free-cutting but more expensive brass. The increase in production and the consequent saving in labor and indirect costs more than compensate for the increased material cost.

328. Plate cams for this machine may be made of common steel, cut on a milling machine, finished by filing, and case-hardened. Cam blanks of **Synthane,** a laminated plastic, may be used with very satisfactory results for short runs or for light cutting pressures, on such materials as plastics, brass and soft metals. The cams can be very quickly cut on a band saw and the sawed edges filed or sanded to the proper contour. Blanks with a bored center hole, a drilled pin hole, and radial layout lines are sold in sets of three.

329. Fig. 22-49 illustrates a **single-spindle automatic screw machine** which has a five station turret with a horizontal axis parallel to the work

spindle, and front and rear cross slides. The machine shown has a maximum capacity of 5¼" diameter bar stock. The principle of operation of this machine is analogous to the Brown and Sharpe Automatic, but the turret and cross slides are controlled by drum cams with adjustable straps; the machine may therefore be used for short-run work by using standard cams and adjustable trip dogs. The tooling for the Cleveland Automatic is relatively inexpensive, since most of the tools are standard and the machine may be quickly set up for new jobs. This machine can also be used for **second-operation work,** since a work-holding magazine may be at-

Cone Automatic Machine Co., Inc.

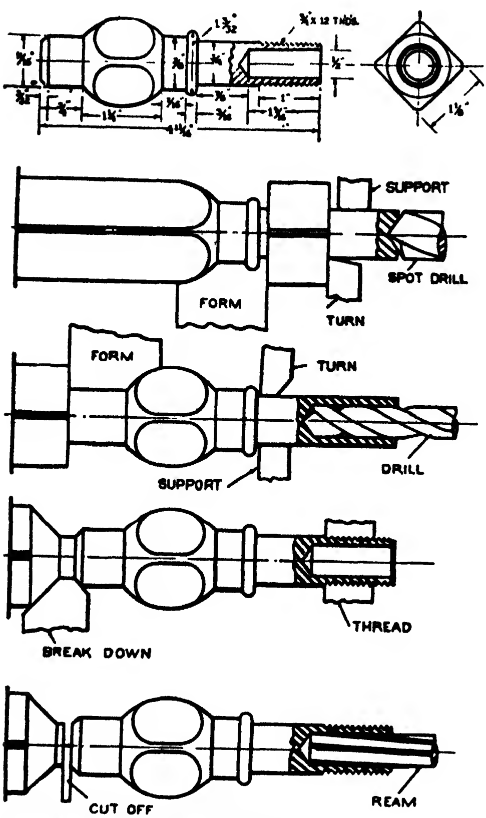
FIG. 22-50. Four Spindle Automatic Screw Machine.

tached to the headstock of the machine for automatically presenting partially-finished work to the spindle for a second series of operations. Magazine attachments for handling small castings or forgings are also used to some extent.

330. Multiple-spindle automatic screw machines are made with two, four, five, six, or eight spindles for holding bar stock, and all stock is machined simultaneously. A **four-spindle automatic** is shown in Fig. 22-50. The spindles rotate in a spindle carrier which indexes around the main drive shaft that passes through the center of the carrier and drives the spindles. The turret slide carries four sets of end-working tools and can advance, feed and return in a direction parallel to the spindle axes. The machine also has two front and two rear cross slides; in Fig. 22-50,

the tool in the lower front cross slide acts on the stock at the first station, and the tool in the upper front cross slide acts at the fourth or last station.

Fig. 22-51 illustrates a **threaded part** made from **square bar stock,** and shows a sequence of operations performed on the machine illustrated in Fig. 22-50. At the first turret station a forming tool held on the lower front cross slide forms the work; a turning tool with a support or roller back rest on the end-working tool slide turns a portion of the diameter; and a spot drill held in the drill holder at the same station spots the work for the subsequent drilling operation. In the second position a forming tool held on the lower rear cross slide completes the forming operation; a turning tool completes the turning operation; and the hole is drilled. In the third position a breakdown tool is used for chamfering the work and bevelling the forward end for the next piece, and the thread is cut. At the fourth station the drilled hole is reamed to size and the part is cut off. The stock is then advanced against a swinging stop and the cycle is complete.



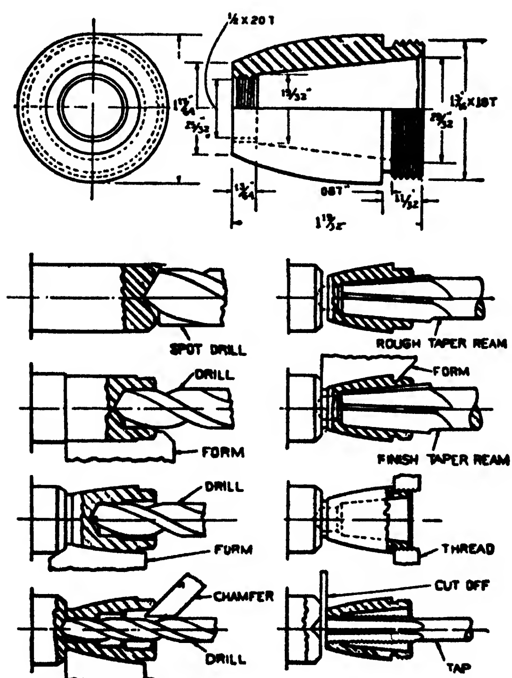
Cone Automatic Machine Co., Inc.

Fig. 22-51. Operational Sequence on a Four-Spindle Automatic.

A multiple-spindle screw machine produces one finished part for every indexing movement of the spindle, or in the case of a four-spindle machine, four parts per complete cycle of the spindle carrier. The total production time for one part is equal to the time required to perform the longest single operation plus the indexing time. The successive turning operations at stations 1 and 2 illustrate the **principle of operational divisibility** described in Section 321; the turning operation, if handled at one station, would take far more time than any other operation, and is therefore completed in two stages.

Cone Automatic Machine Co., Inc.

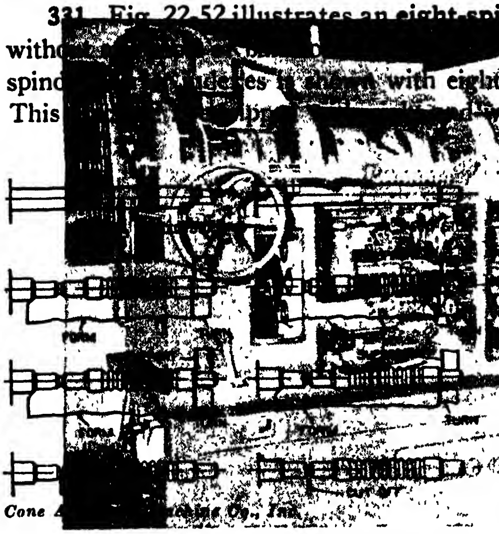
FIG. 22-52. Eight Spindle Automatic Screw Machine.



Cone Automatic Machine Co., Inc.

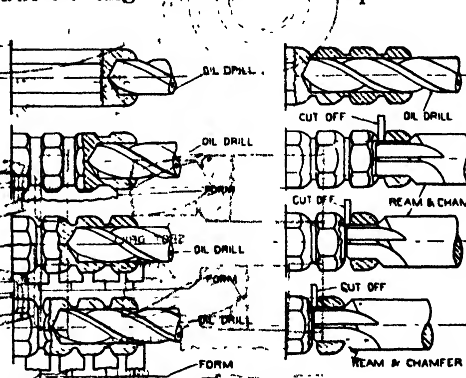
FIG. 22-53. Operational Sequence on an Eight Spindle Automatic.

331. Fig. 22-52 illustrates an eight-spindle automatic screw machine with[illegible] carrier which rotates as the spind[illegible] with eight tubes for bar stock at the left. This [illegible] stations, each opposite [illegible] spindles, and six cross slides for forming and cutting-[illegible] tools, three [illegible] the front [illegible] three at [illegible] of the back. [illegible] Fig. [illegible] illustrates [illegible] machined pa[illegible] its operational seque[illegible] the first [illegible] to the stop [illegible] spotted [illegible] the second [illegible] tially formed [illegible] forming tool, and the largest portion of the hole is drilled by a 3/4″ drill. Forming continues at the third position and the hole is drilled deeper with a 5/8″ drill. In the fourth position the forming continues and the hole is finish-drilled with a $\frac{35}{64}$″ drill and chamfered by a chamfering tool held in the turret slide. In the fifth position the hole is rough reamed with a taper reamer. The forming is completed and the hole is finish-taper-reamed at the sixth position. The external thread is cut with a self-opening die head at the seventh position. In the eighth position the internal thread is cut with a solid tap held in a tapping attachment, and the piece is cut off by a cross slide tool, completing the cycle.



Cone Automatic Machine Co., Inc.

Fig. 22-54. Multiple Production on an Eight-spindle Automatic.



Cone Automatic Machine Co., Inc.

Fig. 22-55. Producing Three Nut Blanks per Index.

332. Fig. 22-54 illustrates a sequence of operations in which the **eight-spindle automatic is handled as though it were two-four spindle machines.** Two completed parts are produced for every index of the spindle carrier. Two identical sets of tools are used; the stock is fed out in the first and fifth positions simultaneously; in the second and sixth posi-

tions the bars are rough-formed and the ends rough-turned from the cross slides and turret slides, respectively; in the third and seventh positions similar finishing operations are performed; and the parts are cut off in the fourth and eighth positions. Fig. 22-55 illustrates another method of multiple production whereby three hexagonal nut blanks are produced for every index of the spindle carrier. Successive drilling operations are performed at the first five positions, and the three nuts are rough-formed at stations 2 and 3, and finish formed at station 4. The first nut is reamed and chamfered and then cut off at station 6; the other two are finished at stations 7 and 8. Multiple-spindle automatics may also be equipped with magazines for second-operation work.

333. Multiple-spindle automatics are used for extremely high production, complicated work, or where a great deal of metal is removed. Overhead costs on multiple-spindle machines are usually higher than for single-spindle machines. Single-spindle machines are credited with more accurate work. The application of the principle of operational divisibility, however, is confined to multiple-spindle machines, and results in prolonged tool life as well as increased production rates.

CHAPTER 23

PRODUCTION MILLING AND ALLIED PROCESSES

334. The **milling machine** has long been recognized as one of the most versatile machines in the unit-production system of manufacture. It is equally adaptable to mass-production operations and processes.

Plain and vertical-spindle **column and knee type milling machines** are extensively used for small and medium sized parts in both large- and small-lot production processes. Several other types of milling machines, however, are employed for heavy cuts on larger work where the production rate will justify the use of such equipment.

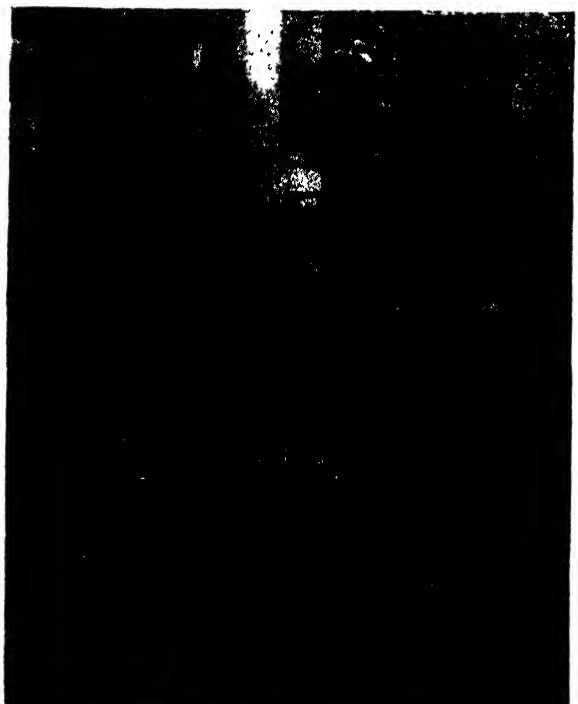
335. Fig. 23-1 illustrates a bed type milling machine taking a climb cut 6" wide and 1/8" deep at a feed rate of 40" per minute. In contrast to the column and knee type of machine, the machine table can traverse and feed only in a horizontal plane in a direction perpendicular to the arbor. The block in which the spindle rotates is carried in the machine head and is adjustable for height. The arbor is supported by two overarms carried in the block. The entire head or housing for the block rests on a slide on the bed so that adjustment perpendicular to the table ways may be obtained.

This machine represents the simplest form of a **series of milling machines** that may be made up of basic standardized **component units** to suit any milling requirement in modern industry. The machine illustrated has one head only, but **duplex** machines with an identical head on each side of the bed, and **triplex** machines with two horizontal-spindle heads and an overhead vertical-spindle head, can be obtained. **Single heads** with **two spindles** in either the same vertical or the same horizontal plane can also be furnished. The heads, table, and the various bed arrangements are standardized so that equipment of this character is not only more readily available, but is also less expensive than special-purpose machinery and can be employed even though changes are made in the part to be manufactured.

Fig. 23-2 shows a **bed type** of machine with three spindles on which face cutters are mounted for milling the top and sides of cast iron meter cases. This design of machine has opposed horizontal-spindle heads that are adjustable for vertical position on fixed columns. The vertical spindle head is adjustable for horizontal position on a bridge member bolted to the tops of the columns. The spindles are carried in *quills* so that axial

adjustment and positioning may be obtained. The table feed and traverse are hydraulically-actuated, and are controlled by trips so that all the operator does is to load and unload the fixtures and start the machine. Two parts are milled on three sides for every table cycle.

336. Fig. 23-3 shows a **single head hydraulic milling machine** with staggered-tooth side milling cutters for milling three keyways in each of five shafts held in an indexing fixture. Two of the keyways in each



Kearney and Trecker Co.

FIG. 23-1. Climb Cutting on a Bed Type Milling Machine 6" Wide, 1/8" Deep Cut—Speed 40" per Minute.

shaft are in alignment, but the third is located about 30° from the center-line of the first two as shown in Fig. 23-4. The shafts are clamped in the fixtures, the operator starts the machine, the spindle carrier head moves down to cutting position, as indicated by *S*, and the table feeds to cut the first keyway as indicated by *F*. The head then rises as shown by *L*, and the table rapidly advances to the next position. This sequence is repeated for the next keyway; the shafts are then indexed for the third keyway before the feed for this cut begins, and the head rises and the table returns

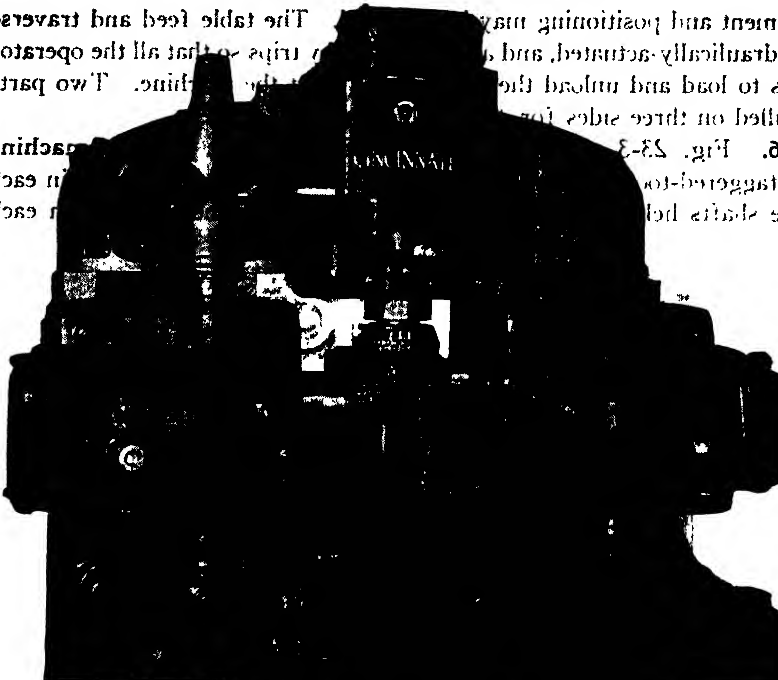


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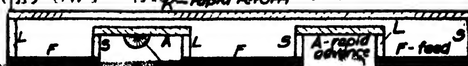
FIG. 2 ... ne.

Cincinnati Milling Machine Co.

FIG. 23-3. Automatic Hydraulic Machine Milling Keyways in Five Shafts.

rapidly to the conclusion of the cut as indicated by D and E. The machine stops and the operator removes the work and resets the fixture.

The hydraulic feed cycle illustrated is representative of the many varied combinations of feed, rapid advance, and rapid return that can be obtained by properly setting trip dogs. Similar feed cycles can also be obtained on column and knee type hydraulically actuated milling machines.



...cle for Milling
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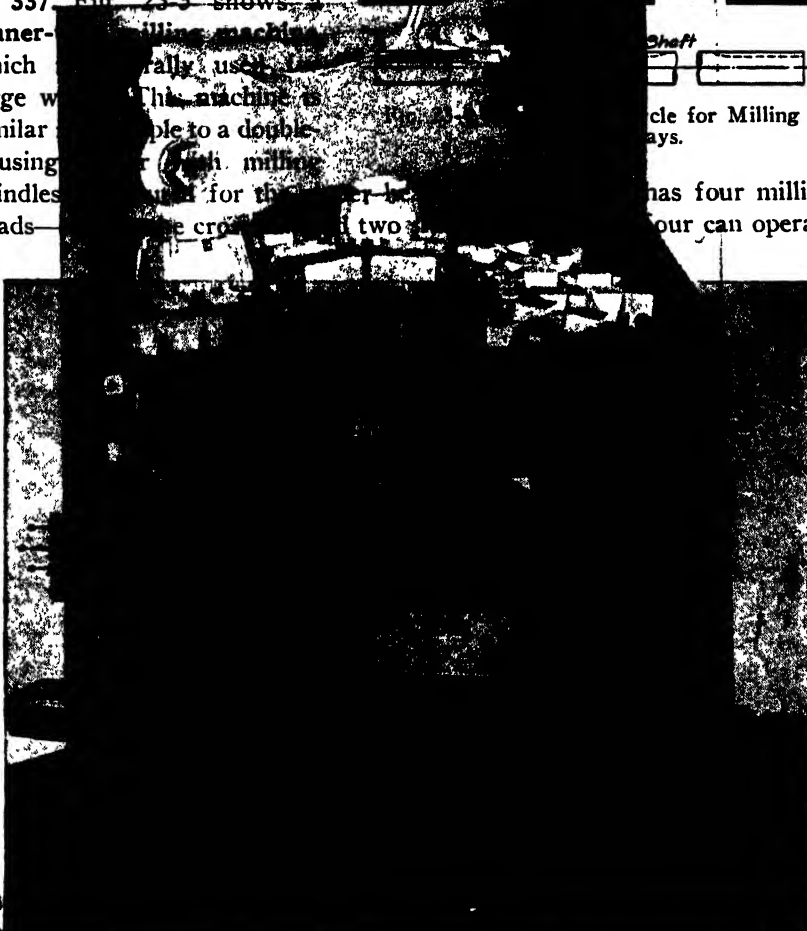
337. Fig. 23-5 shows a planer-type milling machine which ... ally used ... large w... This machine is similar ... ple to a double-housing ... r ... h milling spindles ... for th... has four milling heads— ... cr... two ... four can operate

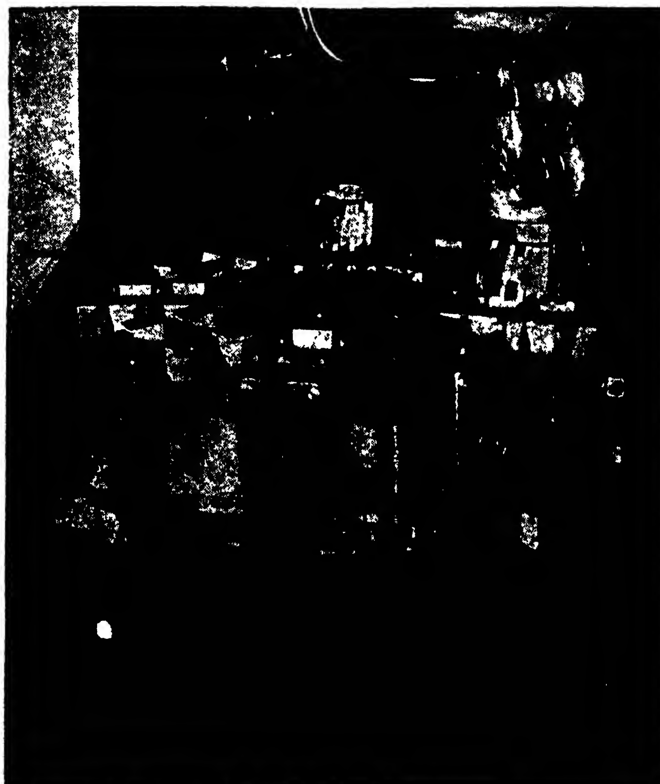


G. A. Gray Co.

Fig. 23-5. Planer-type Milling Machine.

simultaneously. The machine permits a variety of cuts to be taken without the necessity of resetting the work.

338. Fig. 23-6 shows a **two-spindle vertical continuous milling machine.** This machine has a **horizontal rotary table** which is mounted on a saddle so that the table radius may be varied with respect to the axes of the spindles. The spindles are carried in a head which is adjustable vertically on the column of the machine. In the figure, the table is equipped with nine fixtures for milling the joint surfaces of bearing caps, two of which are shown at the left. Two caps are held in each fixture which



Consolidated Machine Tool Corp. of America

Fig. 23-6. Vertical Continuous Milling Machine.

consists of a center block and front and rear clamps fitted with corrugated jaws for holding the rough castings. Both clamps are actuated by the bolt shown.

In this operation the rotary table feeds continuously and one cutter is used for roughing, the other for finish-milling. In some instances, where the work is large but has comparatively small areas to be milled, the table

can be set to rotate rapidly for a portion of its movement and to feed slowly for the remainder of the cycle. In one case the table rotates quickly for 60°, and feeds for 30°, with eight changes of speed in every rotation.

Fig. 23-7 shows a **drum-type milling machine** in which the work to be milled is carried on a horizontal-spindle six, eight, or ten sided drum, that rotates continuously between milling heads mounted on columns on either side of the machine. In the illustration each face of the drum is fitted with locating blocks and two clamping studs for holding the work as it passes between two cutters on one side and three on the other. Machines of this type are used for simultaneously milling the top and bottom surfaces of cylinder blocks, for straddle milling bearing cap surfaces and connecting rod sides, and for similar applications in automotive and other industries.

Consolidated Machine Tool Corp. of America

FIG. 23-7. Newton Drum-type Milling Machine.

339. **Planetary milling** is employed for shaping internal or external surfaces of revolution. The work is stationary and the cutter travels over the surface in a circular path centered at the axis of the work. The planetary milling principle is illustrated in Fig. 23-8 which shows both internal and external applications. The cutter diameter is approximately 20% smaller than the diameter of the work for internal milling and about 20% greater for external milling. The work is clamped to a horizontal rest or to a tailstock, and the rotating cutter enters (or passes over) the work axially, and is fed to depth radially. The cutter then moves in a circular path with a constant depth of cut until it has revolved once about the center of the work. The cutter is withdrawn radially from the cut and removed axially from the work. The process is particularly applicable to heavy

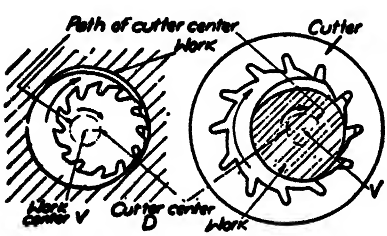
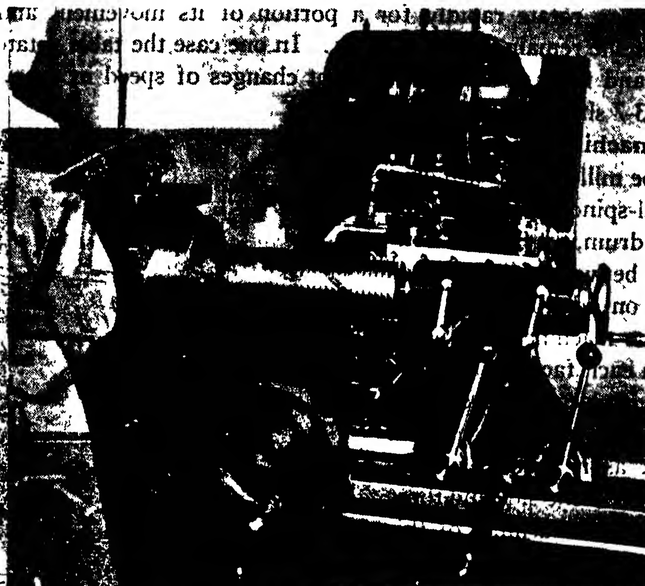
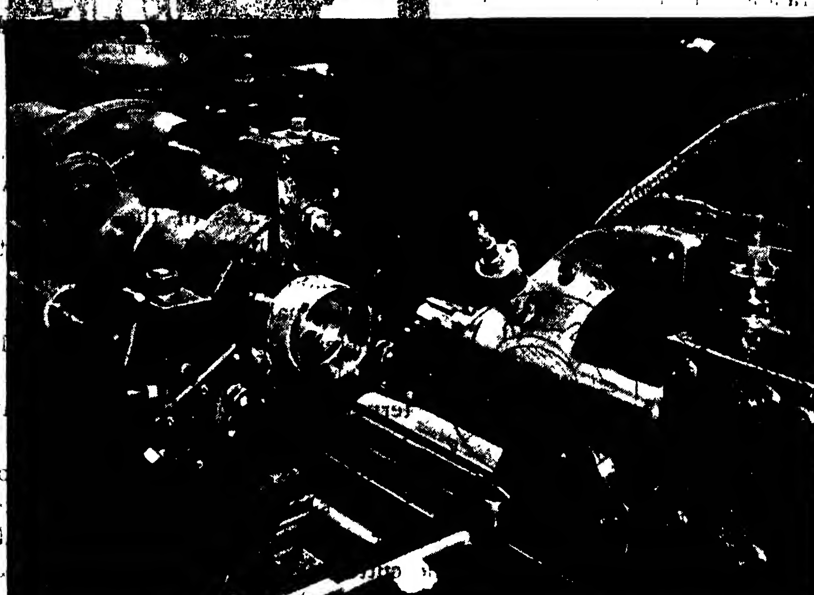


FIG. 23-8. Planetary Milling Principles.



Thread Milling.



The Lees Bradner Co.

Fig. 23-10. Milling an Internal Thread.

of odd-shaped work which cannot be conveniently rotated, and is used for milling bores, milling internal and external surfaces of revolution of irregular profile, and internal and external thread milling.

340. Thread milling machines are used for cutting threads or helices in cylindrical or conical work. A thread milling machine resembles an engine lathe; the work is driven by a headstock spindle, and may be held in a chuck on the spindle nose or between centers as illustrated in Fig. 23-9, or clamped on a faceplate and supported by a steadyrest or roller rest as shown in Fig. 23-10.

The cutter spindle is individually motor driven, and is mounted in a head on a carriage whose motion is controlled by a lead screw geared to the headstock spindle so that these elements will maintain a desired motion ratio. The axis of the cutter spindle head lies in a vertical plane parallel to the axis of the work, but may be swivelled so that the cutter is tangent to the helix angle of the thread to be cut. Fig. 23-9 illustrates **external threading**; a hole-type cutter mounted on an arbor is used, and threads may be completely finished by taking one cut, although two cuts, one roughing and one finishing, are generally employed. This machine is shown milling threads in a large screw for a press brake.

Goddard & Goddard Co., Inc.
FIG. 23-11. Special Interlocking Cutters.

The **internal thread milling operation** illustrated in Fig. 23-10 shows the application of a shank-type cutter of width sufficiently great so that the thread being cut is finished in one and a fraction revolutions of the work. The operation illustrated in this picture is one of milling a thread in a landing gear component in the plant of a prominent aircraft manufacturer.

341. Milling cutters and fixtures are fully as important as the milling machine itself in mass-production processes. Standard milling cutters described in Chapter 13 are extensively used for production milling, and parts should be designed to use such cutters whenever possible. Surfaces of irregular contour may be milled with form-type cutters, and tool and cutter manufacturers are generally able to design and furnish special cutters at short notice. Two examples of such cutters are shown in Fig. 23-12 and 23-13.

342. Fig. 23-11 shows an assembled **profile-type cutter unit, and** Fig. 23-12 shows the disassembled cutters and the special arbor and nut that was supplied with the cutters. This unit is used for milling saw-tooth rack sections for a steel mill cooling bed; the cutters are assembled on the

Goddard & Goddard Co., Inc.

Fig. 23-12. Disassembled Cutters.

special arbor and are keyed in place and held by the nut. The arbor is bolted to the spindle nose of a vertical milling machine. It should be noted that interlocking cutters are used in order to obtain a sharp external corner on the work.

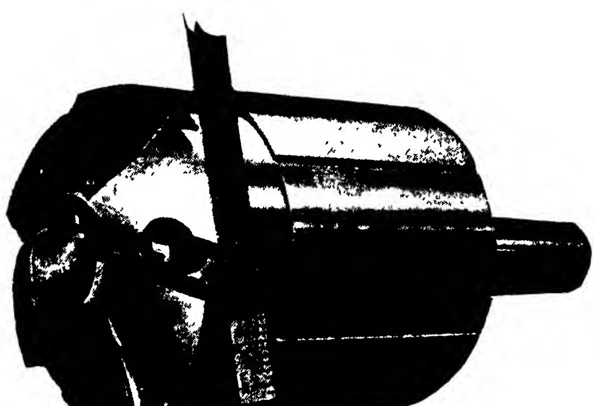


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Fig. 23-13. Form Type Cutter.

Fig. 23-13 shows a special **form-type cutter unit** for milling the large concave spherical surface and the small convex spherical surface on the parts shown in Fig. 23-15. Fig. 23-14 shows the two cutters and the cutter body, which has a self-holding taper shank for use in a drill press.

343. Milling fixtures are used for locating and holding work and are similar to drill jigs, but have no media for guiding the cutting tool. Fixtures are generally fastened rigidly to the table of the milling machine, and adjustment for position is generally made by moving the machine table.

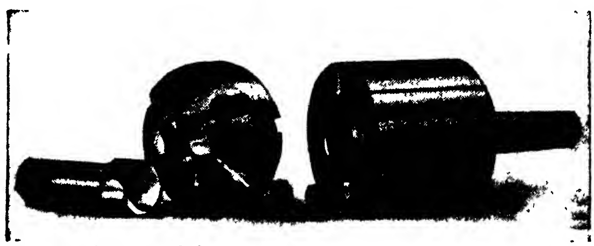

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FIG. 23-14. Disassembled Form-type Cutters.

Comparatively simple, inexpensive milling fixtures can be made by fitting a milling machine vise, similar to the vise shown in Fig. 10-14, with **false jaw plates** for locating and holding the work. The jaw plates supplied with the vise are removed and false jaws substituted and held in place with the jaw screws.

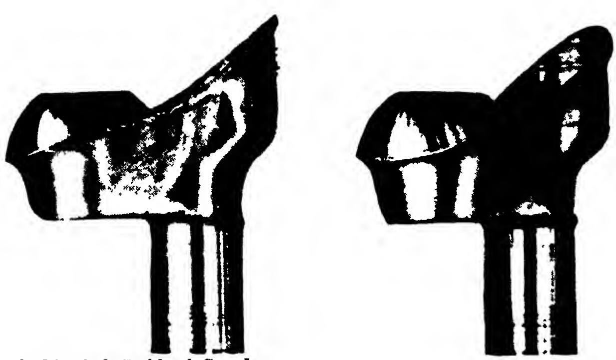

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FIG. 23-15. Part with Spherical Surfaces.

Fig. 23-16 shows a set of false jaws for locating and holding a small crank arm. The part is previously drilled, and is located on two pins in the false jaw plate *S* on the fixed jaw of the vise. (The pin at the left is employed for vertical location only.) Plate *S*, and plate *M* on the movable jaw of the vise, have special profiles to support the work adequately. The right side view of these false jaws shows how far the vise must be opened to remove the work, which will require several turns of the vise screw. The

lower design, Fig. 23-16, shows a set of false jaws fitted with a latch L which swings on a fulcrum pin Q attached to jaw M. As soon as the pressure on the work has been released by a fraction of a turn of the vise screw the latch L can be swung out of the way, as shown in the front view of the jaw M and the work can be removed. The stop pin T supports the latch in its operating position.

Fig. 23-17 shows a part that is located by two of its previously-machined perpendicular surfaces, and is held in place by the pressure of the movable jaw and by an auxiliary clamping screw A at the right. The locating plate R is screwed and doweled to the false jaw plate S on the fixed jaw of the vise. The screw A

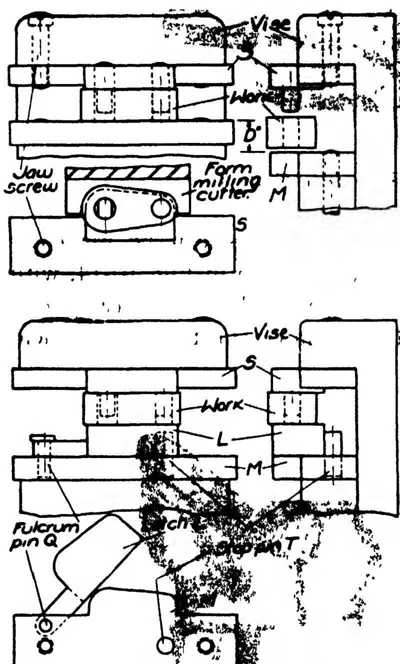


FIG. 23-16. False Jaw Applications.

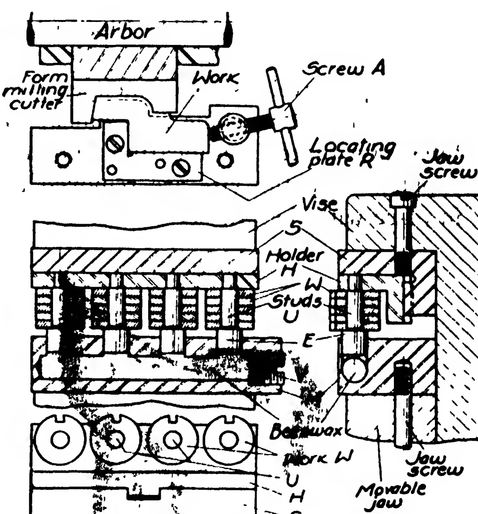


FIG. 23-17. Vise Jaw Fixtures.

is threaded through a stud attached to S and is set at an angle to the horizontal so that the pressure exerted by it will act downward and to the left. In operation, the part is placed on R, clamped with the movable jaw, and then clamped with A.

Fig. 23-17 also shows a set of false jaw plates for holding twenty plain washers so that a locating slot can be milled in them. There are four studs U, each holding five washers; the studs are attached to a holder H which has an integral key that fits into a groove in the base of the jaw plate S. Two holders H are supplied for every vise so that the operator can load one holder while the other is in operation. In this operation the washers W

have a rather large thickness tolerance, and it would be impossible to clamp the central sets of washers if the thickness of the washers in the end sets were near the high limit. The jaw plate M is fitted with four equalizing pins E, which are a snug fit in their respective holes. The long transverse hole is filled with beeswax or a similar substance which furnishes an equal pressure to all four equalizing pins. The set screw V serves as a closure for the beeswax cavity. By employing this equalizing jaw, all four sets of washers are held with the same pressure, so that the slots may be milled by using four correctly spaced saws on the milling machine arbor. This type of equalizer can also be applied to irregular casting and forging profiles.

344. In **ordering special form cutters,** information as to the position of the work in the fixture as well as dimensional data should be furnished to the tool manufacturer. A cutter drawing similar to that of Fig. 23-17, for example, will show the supplier just which surfaces must be held to close limits; and it indicates that the overall length of the cutter and its maximum diameter are not as important as some of the intermediate lengths or diameters.

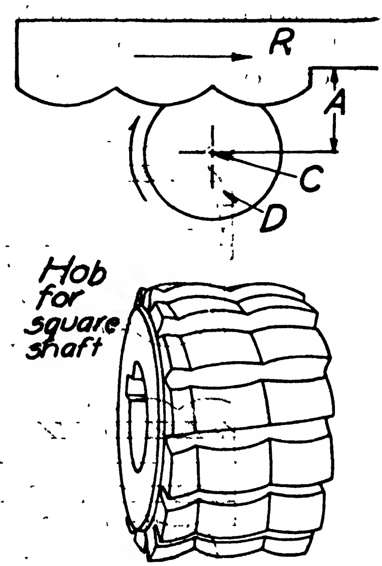


FIG. 23-18. Generating a Conjugate Surface.

345. Hobbing is a process for generating surfaces that are composed of lines having a fixed relation to an axis of rotation. Suppose a circular disc D made of a plastic material rotates about center C, Fig. 23-18, and a bar R with a formed profile is drawn across it at a uniform rate of speed corresponding to the rotative speed of the disc. The formed profile of the bar will generate a reciprocal or **conjugate** profile in the surface of the disc. If the bar is sufficiently long, the entire surface of the disc will have a conjugate profile—in this instance a square—but if the bar is as short as illustrated, it must be reset to complete the operation. If, however, the profile of the bar is embodied in helical form in a rotating cutter, the profile need not be of any great length, nor need the cutter be reset.

Fig. 23-19 illustrates the method of generating a conjugate surface in a disc by using a hob. The hob is illustrated in Fig. 23-18, and has teeth whose profile is exactly like that of the bar. As the hob rotates about its

axis, the movement of the successive tooth profiles across the outline of the disc is analogous to the movement of the bar, and a conjugate profile identical with that of the disc in Fig. 23-18 is cut by the hob. Fig. 23-19 shows eight **stages in the generation of a square;** two sides are shown finished and a third is in process at stage 8. The profile of the work is conjugate to the hob in a plane passing through the axis of the hob and perpendicular to the axis of the work. In order to generate a **conjugate surface** on the work, however, the hob must be set at an angle such that a tangent to the helices of the hob is parallel to the axis of the work, and the hob must feed across the surface of the work at the rate of a few thousandths of an inch for every revolution of the work.

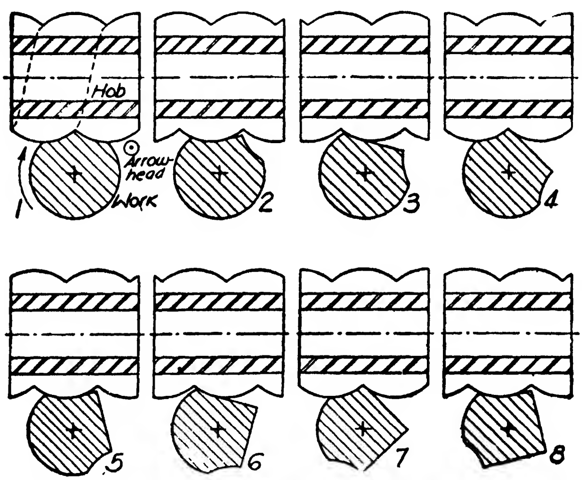


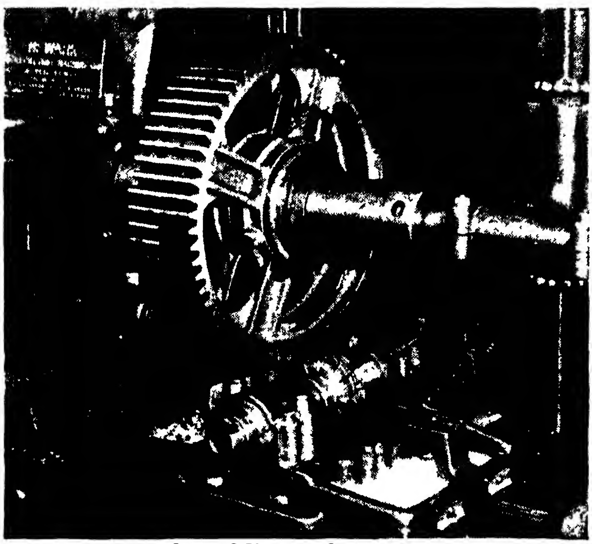
FIG. 23-19. Hobbing Principles and Sequence.

Square and hexagonal shafts, six, eight, and ten-splined shafts, and serrated-end shafts are more effectively produced by **hobbing** than by any other method. Hobbing is also used for cutting ratchets and chain sprockets, but the widest application of the process is to the generation of spur and helical gear teeth.

346. Gear tooth shaping and formation is one of the most important processes in present day engineering practice. Gears with cast teeth, from sand molds, permanent molds, or metal dies are extensively used at the present time for comparatively slow-speed operation. Practically all watch and clock gearing is stamped from sheet metal and gives excellent results for the duty it must perform. Plastic molded gearing is also used to some extent. Gearing for precise operation, or for installation where high speeds and heavy loads prevail, is usually made with cut teeth which are often

finished by various processes to attain high accuracy and comparatively noiseless operation. Since several of the important processes for the formation of gear teeth are milling operations, the subject will be briefly described in this chapter.

347. Cutting gear teeth by using a form-type cutter, as described in Chapter 13, is still an important and extensively used process. Mass-production spur gear form cutting is generally performed on automatic gear cutting machines such as the one illustrated in Fig. 23-20. Two form-



W. A. Jones Foundry and Machine Co.

FIG. 23-20. Gear Cutting Machine.

type cutters, one roughing and one finishing, are used and the process is analogous to cutting spur gears on the milling machine. The cutter slide advances to the work, feeds through for the cut and returns rapidly to starting position. The work then indexes and the cycle of operations is repeated. The roughing cutter has stepped teeth to break up the chips and removes most of the material, leaving just enough metal for the finishing cut.

348. Gears with teeth of almost any form can be used to **generate conjugate teeth in a plastic blank** by rolling the master gear and the blank together at the proper speed ratio equal to the ratio of their pitch diameters. This principle is used in producing hot-rolled gears, in which a master gear is rolled with a heated gear blank. (Good results are obtained but the process is not yet extensively used.) **Involute teeth,**

however, will generate conjugate teeth of *involute* form in the application of this principle. Since a **rack** is an involute gear with a pitch diameter that approaches infinity as a limit, it will also generate ***involute*** teeth in a circular blank. This application is made use of in the gear hobbing process in which a hob whose tooth profile is of rack form is used for cutting spur and helical gears. The hob is illustrated in Fig. 23-21. In **cutting spur gears,** the axis of the hob is set at an angle such that the pitch helix of the hob is tangent to the tooth elements of the gear to be cut; if the helix angle of the hob is 10°, the angle between the axis of the hob and the axis of the work is 80°. (Contrast this relation with that of the worm gear hob in Chapter 13 in which the hob and gear axis are at 90°, which results in a helical worm wheel tooth.) The hob is set to cut to full depth, and feeds slowly across the face of the gear in a direction parallel to the gear axis

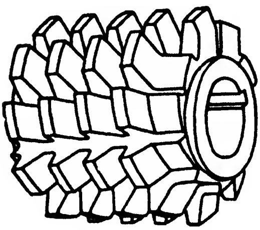


Fig. 23-21. Gear Tooth Hob.

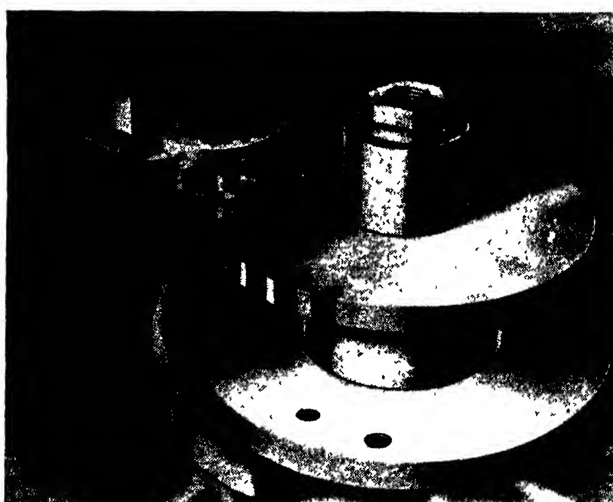


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Fig. 23-22. Gear Shaping Principles.

as the latter rotates. The speed ratio of the work and the hob is equal to the speed ratio of an analogous worm gear set. **Helical gears** are also cut by hobbing; the process is analogous to spur gear hobbing with necessary adjustments for the helix angle, lead and hand of the helical gear.

349. The **conjugate generating principle** is also employed in the widely-used process of **gear-shaping** which is illustrated in Fig. 23-22.

The cutter C is carried on a vertical reciprocating ram, and is similar to a spur pinion; it cuts on its upward stroke, backs away from the work, moves down to starting position, and then moves forward for a second vertical cut. Both the cutter and the work rotate slightly as the cutter descends, at a speed ratio inversely proportional to their pitch diameters. To illustrate, if an 18 tooth cutter is employed for cutting a 36 tooth gear, the cutter will rotate intermittently at twice the speed of the blank. The rotative speed of the cutter determines the thickness of the chip as shown in Fig. 23-23.

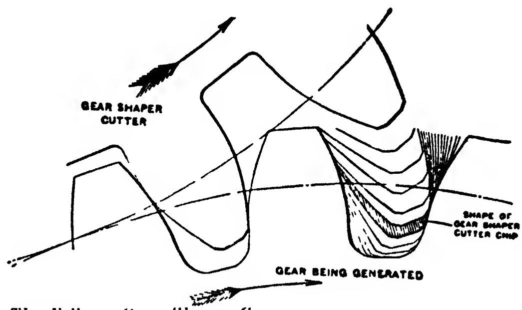

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FIG. 23-23. Gear Shaper Action.

The **gear shaping process** has several advantages over other methods of gear tooth cutting. One cutter can be used for cutting all spur gears of the same pitch; the cutter has a very accurate profile, since it is possible to generate its tooth profiles after hardening by grinding; the cutter automatically corrects any tooth interference in the blank; and the finished gear has a generated profile. Another advantage of the gear-shaping process is that it can be used to cut internal gears, since the length of the cutter stroke need only be from $\frac{1}{8}''$ to $\frac{1}{4}''$ longer than the face of the blank to allow from $\frac{1}{16}''$ to $\frac{1}{8}''$ overrun at the ends of the cut.

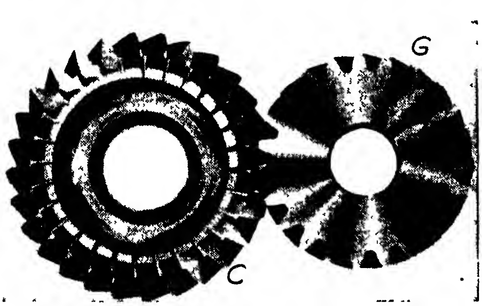

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FIG. 23-24. Helical Cutter and Finished Gear.

350. External and internal **helical gears** may be cut on a **helical gear shaper** in which the ram has a helical motion and oscillates as it reciprocates. A helical cutter C and the finished gear G are illustrated in Fig. 23-24. One cutter may be used to cut all gears of a given pitch, helix angle and hand. Helical gear shapers can cut gears with a maximum helix angle of 30°, but as the ram guides must be changed for every different helix angle, modern practice has standardized two helix angles—15° and 23°—which take care of the usual industrial applications of this type of gear. As each cutter is used for one helix angle only, the

tooth proportions are designed for diametral pitches in the ***diametral plane,*** in contrast to helical gears cut on a milling machine in which gears are designed with pitches in the ***normal plane*** in order to use standard spur gear form cutters. This procedure makes it possible to replace spur gears of a given size with corresponding helical gearing, at the same center distance.

Another type of machine which operates on an essentially similar principle is used for cutting **herringbone gears with continuous teeth** that have sharp apices. As illustrated in Fig. 23-25, the cutting is done by two opposed cutters of opposite helical hand which oscillate and reciprocate, and also revolve slowly in unison with the wheel blank. The generating action of these cutters is such that, as each cutting tool slowly revolves out of engagement with the tooth space, it cuts a chip which tapers off to an infinitesimal thickness and thereby cleans out the corners perfectly.

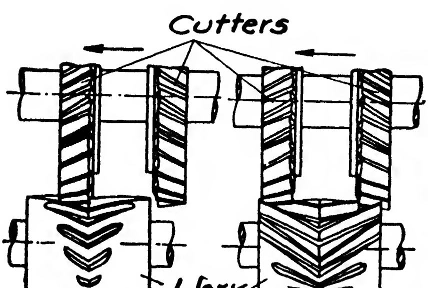

Fig. 23-25. Cutting Continuous Tooth Herringbone Gears.

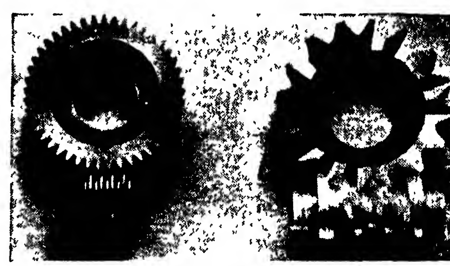

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Fig. 23-26. Generated Thread and Worm.

351. Pinion type cutters are also used for **thread and worm cutting.** Illustration *A,* Fig. 23-26 shows a cutter of this type used for cutting **Acme threads.** The cutter and work rotate at the proper speed ratio and the cutter also has a rectilinear motion parallel to the axis of the work. Illustration *B*, at the right of Fig. 23-26 shows a **globoidal worm** for a steering gear and the pinion-type cutter used for its generation. The cutter and work rotate at the proper speed ratio, but the cutter axis remains fixed with respect to the midplane of the worm.

In many cases it is possible to **generate irregular shapes** on a gear shaping machine by using a special cutter designed to fit the work. One example of this method of machining is shown in Fig. 23-27, which illustrates a small ratchet pawl *P* and the shaper cutter *C* for machining its entire left profile. The machine was provided with a four-station fixture so that four pawl blanks are located and clamped at one time. The cutter is made with four identical series of lobes so that four parts are produced at one complete revolution of the cutter.

352. Precision bevel gear tooth profiles may be cut by a single point tool guided by a master template. A cutter that can pass through the small end of the tooth space is used, and moves along straight lines which intersect at a point corresponding to the apex of the gear. These cutter strokes are guided and controlled by a large master template of the correct tooth outline. Bevel gears are also generated by a cutter tooth which simulates an imaginary crown gear; the cutter blank is held at such an angle that it theoretically meshes with this crown gear; the cutter reciprocates along

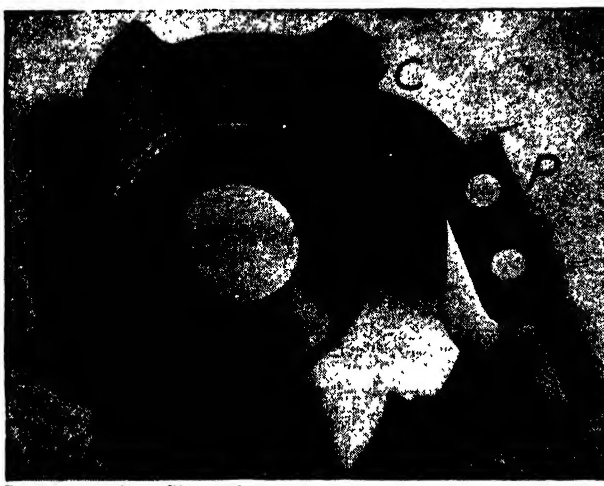

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FIG. 23-27. Ratchet Pawl and Gear Shaper Cutter.

straight lines and oscillates about the axis of the blank so that profiles of the correct form are generated. These two methods produce bevel gears with correct profiles over the entire face of the gear to the same degree of accuracy that spur gears are manufactured.

Spiral bevel and hypoid gear teeth are generated on special machines built for that purpose, by means of a rotating side-cutter tool that simulates the form of a tooth of a mating gear. The rotating cutter machines one tooth space at a time and the work is then withdrawn and indexed for the next series of cuts.

353. Worm gear teeth are generated by a **hob** similar to the one described in Chapter 13, or by a **tapered hob** that feeds *tangentially* to the gear to be cut. Both types of hobs are generally employed in conjunction with automatic gear-cutting machinery in which the gear blank rotates at a speed proportional to the speed of the hob.

354. Gear teeth may be finished after heat treatment by **burnishing, shaving, lapping, and grinding.** There are two methods of grinding gear tooth profiles. One method uses a **form-type abrasive wheel** whose profile is trued by a pair of diamonds moving in an involute path. The gear is mounted on an arbor, and the wheel passes through one tooth space at a time and cuts on both forward and return strokes; the gear is automatically indexed to the next tooth space at the conclusion of one complete reciprocation. The other method of gear grinding employs a flat-sided wheel operating on the **rack principle** to generate the tooth profile as illustrated in Fig. 23-28. A wheel of sufficiently great diameter to permit the gear face to be ground without any axial motion of the work is usually employed, and since a flat-sided wheel can be easily and accurately trued, a product with a high degree of precision results.

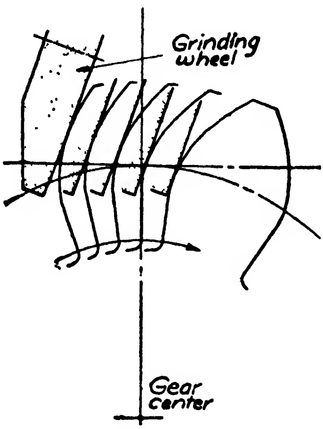

FIG. 23-28. Gear Grinding Principles.

355. Shaving processes are extensively employed for gear tooth finishing. Two examples of gear tooth shaving operations are illustrated in Fig. 23-29 and 23-30. The rotary type of cutting tool illustrated is provided with a series of serrations on the faces of the teeth, which act as cutting edges. The blank to be finished is mounted on an arbor or on a mandrel between centers as illustrated. The cutting tool rotates at high speed and is at the same time rapidly reciprocated across the work. The tool is fed gradually to depth by a feed cam which has a dwell period to insure finishing the gear to the required pitch diameter.

Gear teeth can be shaved by either the **parallel-axes** or the **crossed-axes methods.** The former is generally used for spur gears, particularly cluster gears as illustrated in Fig. 23-29 since the tool can operate into a comparatively narrow recess without interference. The crossed-axes method can be used for finishing spur gears, but is generally used for helical gearing.

356. Lapping is recognized as a highly efficient method of finishing gear teeth after hardening. One method uses a cast iron internal gear lap for finishing external spur gears by a reciprocating motion across the gear face, employing a rotary motion of both the lap and the blank to distribute the abrasive lapping compound. The tooth shape of the lap conforms to the tooth shape of the gear. Another method of lapping employs abrasive lapping wheels in which helical teeth are cut, as illustrated in Fig. 23-31,

which shows an integral gear on a transmission shaft being lapped between centers. The carriage on which the shaft is mounted reciprocates and the

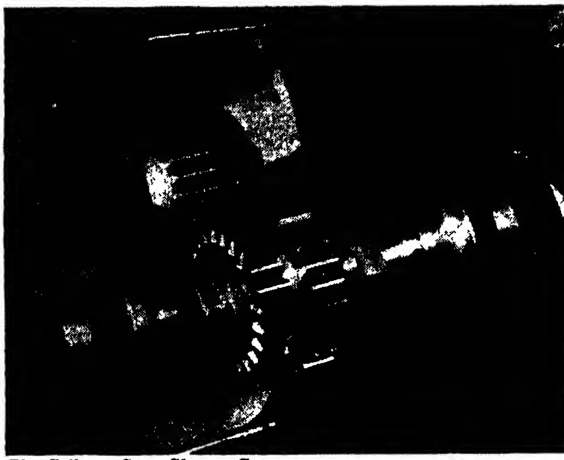

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FIG. 23-29. Gear Shaving, Parallel-axes Method.

abrasive wheels revolve, causing a lapping action which accurately finishes the gear teeth.

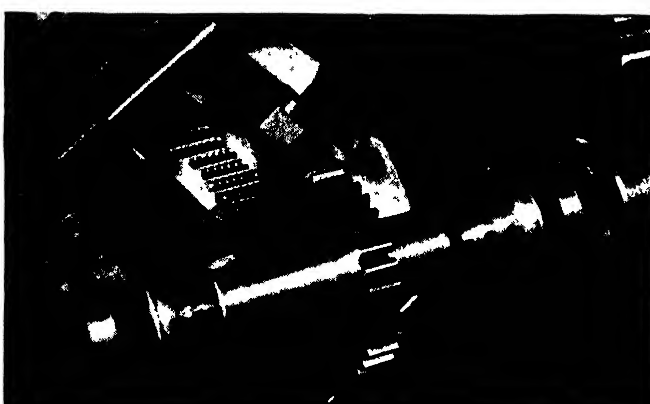

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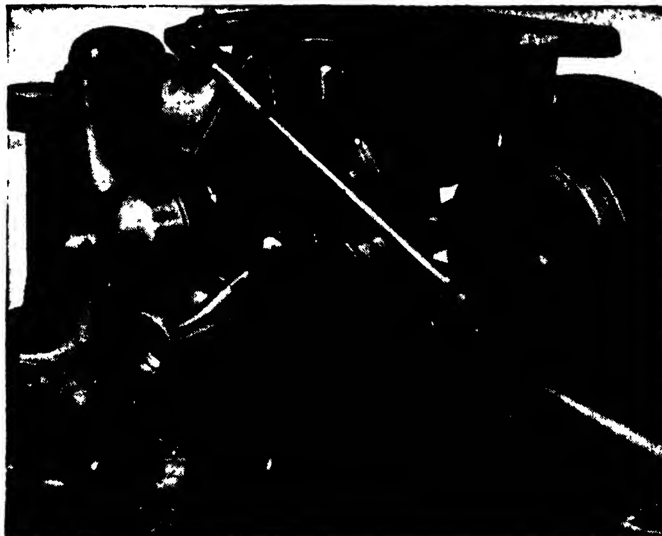
FIG. 23-30. Gear Shaving, Crossed-axes Method.

357. Fig. 23-32 shows a gear burnishing unit for refining and smoothing gear tooth surfaces after finish-cutting. The burnishing is accomplished by rotating the work, shown in the center, between three hard-



Barnes Drill Co.

FIG. 23-31. Abrasive Wheel Lapping Machine for Finishing Gear Teeth

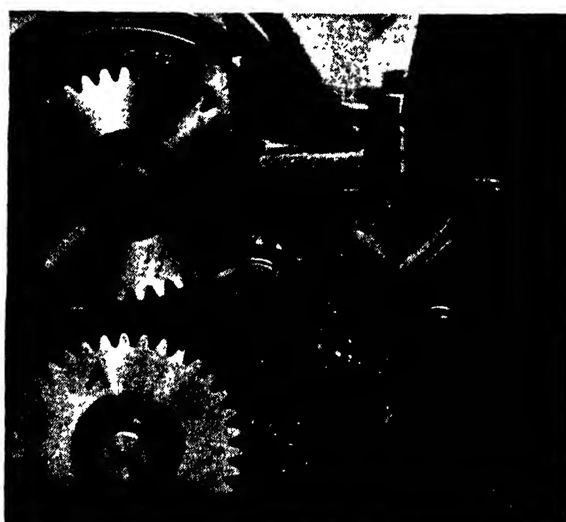


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FIG. 23-32. Gear Burnishing.

ened and ground burnishing gears. The lower left gear A is power driven, the upper left gear B rotates on a fixed stud, and the third gear C at the right is adjustable for burnishing gears of different diameters, and is used to apply the burnishing pressure. A lubricant composed of kerosene and light machine oil is used for the process. Burnishing will not correct errors but serves to compress the surface of the teeth and provides a slight surface hardness. As a finishing operation prior to hardening, it can also be used to remove burrs and bruises.

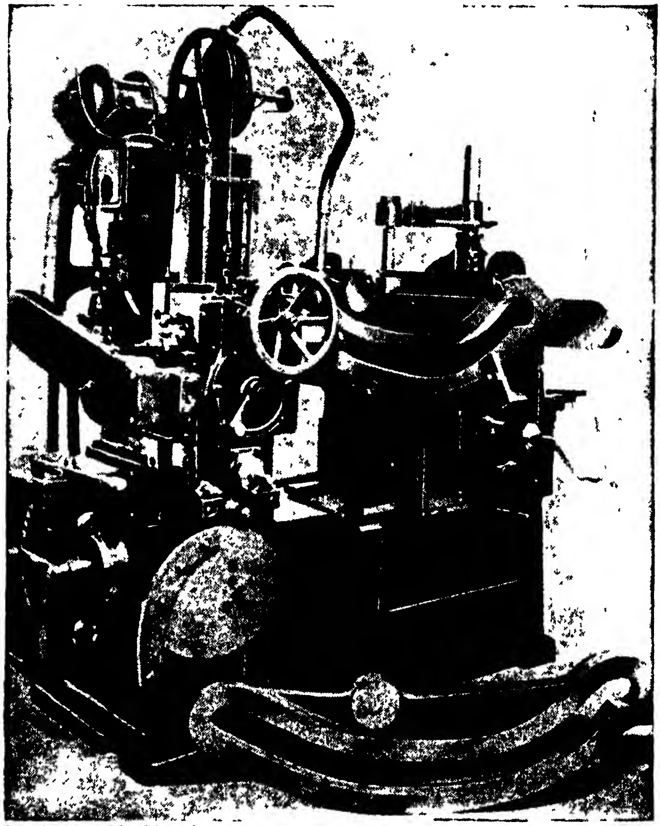
358. Fig. 23-33 illustrates a **production cam milling machine** for milling various types of cams by following a former or **master cam.** M is a master plate cam which actuates the cutter slide S by a roller R. The cutter K is carried in a spindle in S, and cuts the cam groove in the cam C as the latter rotates about the axis of the arbor A and the faceplate carried on the work spindle in the work head W. Fig. 23-34 shows the same machine with the rotary arbor removed. The cutter is milling a long curved slot in a part which is held on the work-head by C-clamps, while the work-head feeds across the bed of the machine.

Rowbottom Machine Co.

FIG. 23-33. Milling a Drum Cam on a Cam Milling Machine.

The machine is also used for cutting plate cams by placing the arbor and work spindle axes in a horizontal position parallel to and in the same vertical plane as the cutter axis. A different former or master is of course required for every different cam that is cut.

359. Broaching is a machining process whereby one or more cutters with a series of teeth are pushed or drawn entirely across a surface consisting of straight-line elements, and is analogous to single-stroke filing. Broaching is done on manually-operated presses, on pull-screw machines, or on hydraulically-actuated broaching machines or presses. Fig. 23-35 shows a **screw-actuated broaching machine** arranged to cut keyways in milling machine arbor collars. The **broach** has teeth which increase in height towards the right end, and is held in the screw socket by a taper cotter. The first few teeth on the broach are low to permit the small end of the tool to be passed through the cylindrical hole in the work; the inter-



Rowbottom Machine Co

FIG. 23-34. Milling a Curved Slot on a Cam Milling Machine.

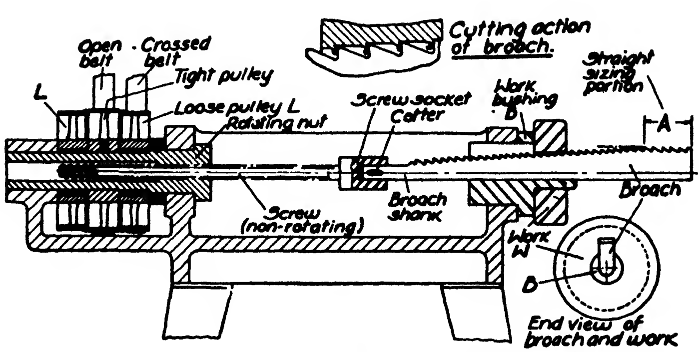
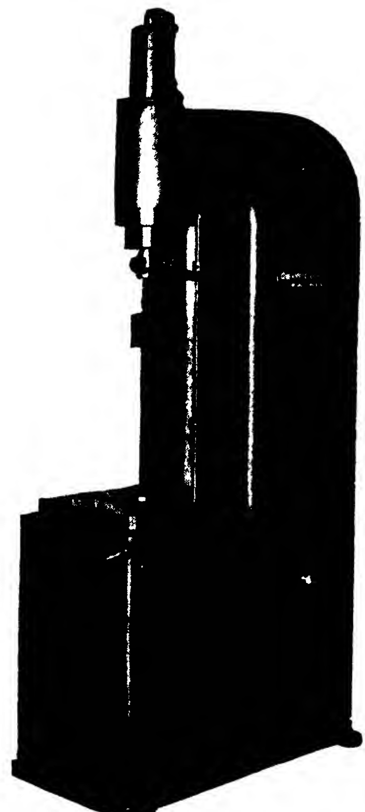


FIG. 23-35. Horizontal Screw-actuated Broaching Machine.

mediate teeth remove most of the metal; and the last few teeth finish the surface to size. Each tooth removes an equal amount of metal as illustrated in the enlarged detail view.

The **broach** is drawn or pulled through the work by the non-rotating screw which receives its axial motion from a rotating nut driven by a tight pulley. The machine is driven by a pair of belts; the open slow-speed belt is used for the broaching operation, and the crossed high-speed belt for returning the pulling screw to position. The belts are automatically shifted to the left by a control shaft.

The work *W* is placed on an arbor or **work bushing** *B*, which holds the work and serves as a support for the broach. One advantage of the broaching process is that the cutting action of the broach itself serves to hold the work in place. In this operation the bushing locates the work, but the broach holds it against the supporting face of the bushing. The broach completes the keyway cutting operation in one pass; the cotter is removed and the broach withdrawn from the work by hand; the pulling screw returns to position while a new part is placed on the work bushing *B*. The shank end of the broach is passed through the work and locked in the screw socket with the cotter.



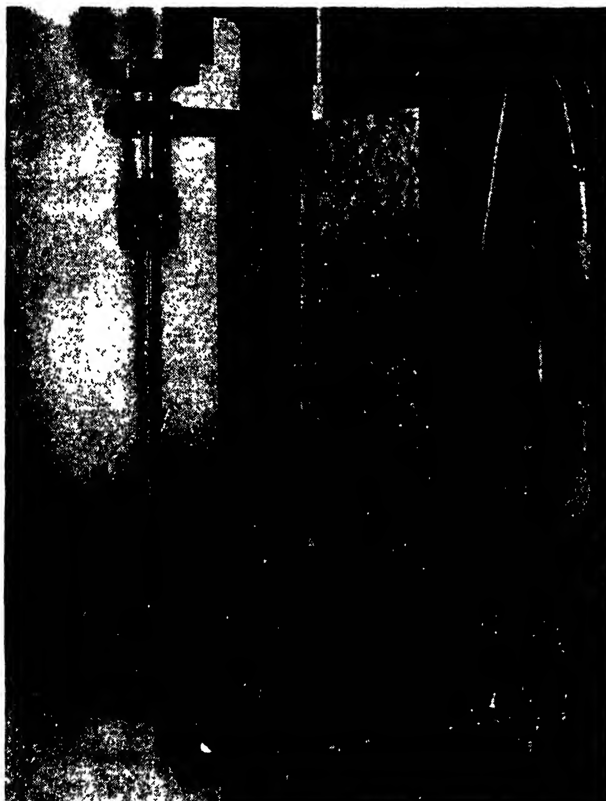
Colonial Broach Co.

FIG. 23-36. Vertical Hydraulic Press for Push Broaching.

360. Hydraulically-actuated broaching machines for push or pull broaching are made in either horizontal or vertical types. Fig. 23-36 shows a vertical hydraulic press which is used for push broaching. The ram at the top of the column is actuated by an hydraulic piston and cylinder. The work platen is removable so that special clearance holes may be machined in it for special broaching set-ups and fixtures. Presses of this type are made in capacities from one to ten tons, and are used for press fits in assembly operations as well as for broaching applications.

Push broaching is usually performed on vertical machines with broaches that are comparatively short to insure stiffness. They are or-

dinarily employed where only a small amount of metal is to be removed. A set of several short push broaches may be required to remove the same amount of metal that one long **pull broach** will handle. Short broaches are used whenever possible, however, as they are easy to make, harden, and handle. The manually-operated arbor press illustrated in Fig. 11-28 is sometimes used for push broaching on light jobbing or repair work.



Colonial Broach Co.

FIG. 23-37. Broaching Gear Bores Automatically.

361. Broaches instead of **reamers** are often used for finishing round holes; since the final sizing of the hole is done by the last few teeth which remove very little material, the broach will hold its size for a much longer period than a reamer. Such elements as connecting rod and connecting rod cap bolt holes are finished in this manner; the assembled rod and cap is held in a vertical position, and two or four pull broaches (depending upon the number of holes) are drawn through simultaneously.

Fig. 23-37 shows a press similar to that of Fig. 23-36 fitted with an **indexing device** for reducing the manual handling of parts to a minimum. The operation consists of finish-broaching the bores of helical transmission gears. The gears are merely dropped into *pot-chucks* on an indexing table, and the ram pushes the broach through the hole and returns to the top of its stroke. The table then indexes automatically through one-sixth of a turn, and the broaching operation is repeated on the next gear. The finished parts drop out of the pot-chuck on the far side of the machine at a production rate of 450 broached gears per hour. All the operator is required to do is to drop the gears into the pot chucks.

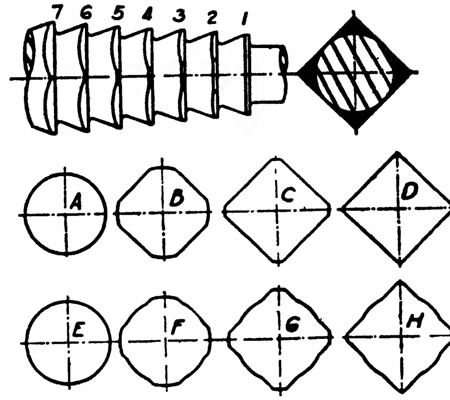
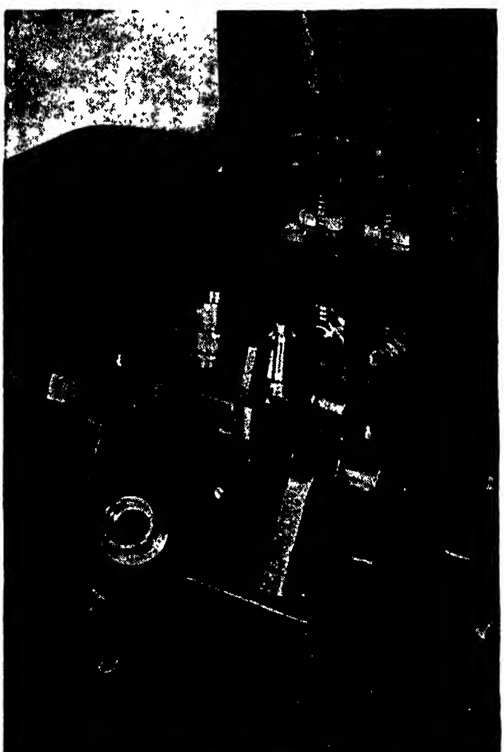


Fig. 23-38. Square Hole Broaching.



Colonial Broach Co.

Fig. 23-39. Cutting Slots in a Semi-automatic Transmission Gear.

Attention is called to the two semi-spherical "teeth" at the top of the broach in Fig. 23-37. These serve as burnishers for the gear bore, compress the metal slightly, and smooth out surface fuzz. **Burnishing broaches** are used to some extent, particularly in finishing small cast iron holes. One manufacturer finishes the bore of small cast iron bushings by reaming them approximately .001″ undersize, and then forcing a **hardened steel ball** of the correct diameter through the hole. The oper-

ation is performed on a special machine, and the bushings and balls are positioned automatically. The ball process cannot be used, however, for bores that have oil grooves or radial oil holes in them.

362. Broaches are extensively employed for machining square and hexagonal holes and splined shaft fittings. Fig. 23-38 illustrates a **square hole broach** which transforms the round hole shown at *A* to the square hole shown at *D*. Tooth number 1 fits the round hole *A; B* shows the cutting effect of tooth 3, and *C* the cutting effect of tooth 5, while *D*

American Broach & Machine Co.

FIG. 23-40. Surface Broaching the Ends of a Transmission Case.

shows the finishing effect of tooth 7. (In actual practice, of course, more than seven teeth are required for an operation of this character; the intermediate teeth between 1 and 2, 2 and 3, etc., have been omitted for the sake of clarity.) An **alternate design** and process are shown at *E, F, G,* and *H*. The hole at *E* is drilled slightly larger than the side of the square and the final teeth of the broach do not remove all the material in the corners. The design at *H* is practically as effective for power transmission as the design shown at *D,* and may be more easily broached.

363. Surface or external broaching is used on many types of surfaces. In many instances the broaching machine competes effectively with the milling machine and the planer in this type of work. Fig. 23-39 shows a **vertical broaching machine** for **cutting slots** in a gear blank for a 1941 semi-automatic automobile transmission. One such blank is shown in the fixture on the table of the machine; another is shown in the foreground. The slots were held to a limit of .003″ for size and .002″ for centrality with the bore. In order to attain the required production rate of 240 parts per hour, a dual fixture and two broaches were used on a single ram machine.

The broaches are of floating construction and are pulled through a broach guide and the work by pullers connected with an hydraulic ram in the base of the machine. In operation the parts are placed over studs on the fixture while it is in the position shown. (One stud is shown loaded, the other empty.) The fixture table moves automatically towards the broaches, which causes the fixture to tilt forward, so that as the table finishes its forward movement, the parts are in a horizontal position and their bores are located over the two pilots in the broach guides. The machine ram moves down and pulls the broaches through the guides, and the slots are rough-cut and finish-cut. At the end of the down stroke, the fixture table automatically moves back and tilts the fixture so that the work is vertical. The machine ram then moves up to starting position and the operator removes the two finished parts and places two more over the studs. To eliminate manual chucking, two spring-actuated fingers are provided to hold the parts in place on the studs until they have been locked against the work pilots on the broach guides.

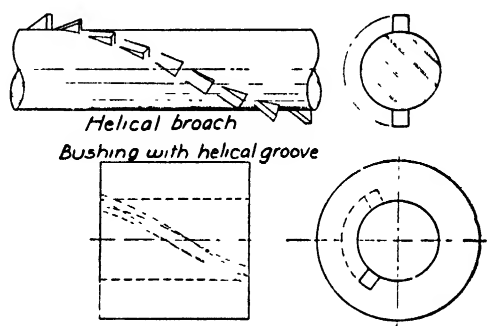


Fig 23-41. Helical Broaching.

Fig. 23-40 shows a special **hydraulic surface broaching machine** with two broaches for finishing the two ends of an automobile transmission case. The broaches are mounted in a common holder which in turn is mounted directly to the machine ram. The work is held in an hydraulically-actuated fixture.

Rotary continuous surface machines are used for broaching small parts in large quantities. **Horizontal machines** with an endless chain, on which work-holding fixtures are mounted, that carries the work between and underneath horizontal surfacing broaches, are used for large-scale production. The fixtures are usually made self-clamping, and unclamp au-

tomatically to drop the work out of the fixture after it has passed through the broach position. **Duplex vertical broaching machines,** which are fitted with two broaches and two sets of fixtures so that one broach may be cutting while the operator unloads and loads the other fixture, are also applicable to many parts.

364. Fig. 23-41 shows a bushing with a helical groove which is cut by using a **broach with helical teeth.** The axial advance of the broach through the work must be accompanied by a rotary motion of the broach in the ratio of one rotation for every axial movement equal to the lead of the helix. This process is used in **gun-barrel rifling,** except that a broach with several series of teeth, to complete all the rifling grooves at one operation, is used instead of the single groove broach illustrated.

CHAPTER 24

PRODUCTION SURFACE FINISHING PROCESSES

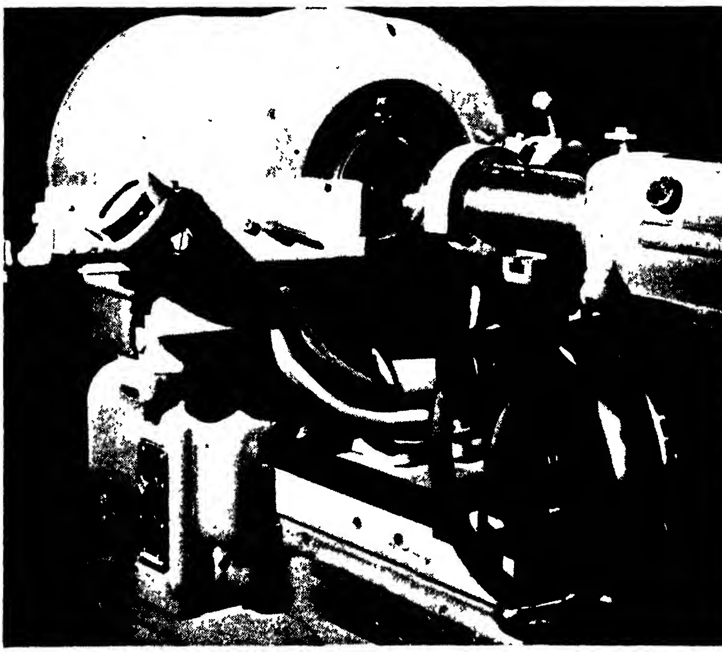
365. Many of the **grinding machines** described in Chapter 16 are used for the mass-production of precision parts. Some of these machines are fitted with special chucks or work-holding fixtures to facilitate loading and unloading; others are equipped with special sizing devices and stops for grinding duplicate work; and others in some instances may be fitted with devices for semi-automatic control. In addition, there are many varieties of single-purpose grinding machines that can be adapted to a variety of work of the same general character.

366. Fig. 24-1 illustrates an **internal grinding machine** equipped **with a dial indicator,** which has a diamond-pointed finger that is in contact with the hole in the work at all times while grinding, although it is automatically swung out of the way as the wheel head withdraws to *rest position* to allow removal and chucking of the work. The use of the indicator eliminates frequent hand gaging of the hole, informs the operator when the hole is finished, and enables him to true and dress the grinding wheel at any predetermined point before finish size is reached, a vital factor in grinding to close limits or getting a fine finish.

The **Heald Gage-matic** is similar to the internal grinder shown in Fig. 24-1, but is equipped with a gage at the rear of the work and with automatic operating units for the gage and wheel head. In operation, the chuck is loaded and the machine started by hand. The wheel head is rapidly brought up to the work and the table slows down to roughing speed for the rough-grinding operation. The gage tends to enter the hole from the rear as illustrated in Fig. 24-2 each time the wheel recedes from the work. The machine continues to grind until the hole has very nearly reached finish size when the roughing gage *R* enters the hole. The table stroke then changes to short strokes for truing; the truing diamond drops into position and the grinding wheel is dressed and trued. The table begins feeding again, generally at a different rate of feed, and the grinding wheel speed is changed to a finishing speed. When the hole has reached finish size, the second gage *F* enters, as illustrated, the wheel rapidly withdraws from the work, and all the units go to a rest position. The operator then removes the work and the cycle of operation is complete.

The **Nortonizer** is an electrical gage for controlling the accuracy of cylindrical grinding. The gage has three contact points which ride on a

transverse circle of the work as the grinding wheel feeds in. When the correct diameter is reached, an electrical contact is made which stops the wheel feed and automatically lifts the gage from the work. The wheel remains in contact with the work for a short period to *spark out* and then recedes rapidly to a position which facilitates reloading of the work. The device virtually eliminates subsequent inspection since parts are finished to



Heald Machine Co.

FIG. 24-1. Grinding the Bore of an Airplane Engine.

a tolerance of .0003″. Wheel wear has no effect on the gage operation, and the work need not be prepared to very close limits prior to the grinding operation. The Nortonizer can be applied to hand as well as power traverse cylindrical grinding machinery.

367. Roll grinding machines are similar to cylindrical grinders, but are generally more massive and rigid in order to produce the accuracy and finish that is required in printing machine and sheet mill rolls. Roll grinders are made in work sizes from 20″ to 28″ in diameter and 8′ to 16′ in length.

Crankshafts may be ground on plain cylindrical grinding machines arranged for such work or they may be ground on specialized **double-head crankpin grinders.** The crankshaft is supported and driven by a

work head at each end of the part to minimize torsional strains in the work. The crankpins are generally ground by the plunge-cut method.

Fig. 24-3 shows an **automatic machine** grinding the **thread** of an index worm for a 200 × 88″ helical gear generator. The outside diameter of the thread is 10″, the thread angle is held to a limit of one minute, and the lead accuracy is held within a limit of .00025″ for the 12″ thread length. The machine is similar in principle to a cylindrical grinder, although the work in Fig. 24-3 is shown supported at the right end by two ball-bearing steadyrests. The truing device for the wheel is equipped with three independently and automatically operated diamonds for dressing and truing the grinding wheel to any standard and many special thread forms. The truing device permits the use of generated formers for correcting the flank of the thread profile, which is necessary on threads with high helix angles.

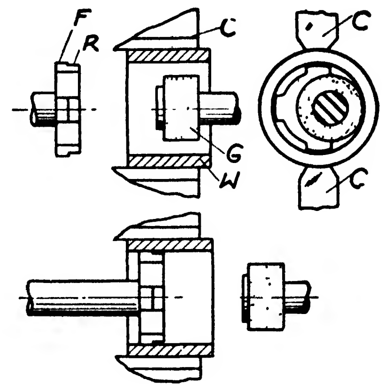
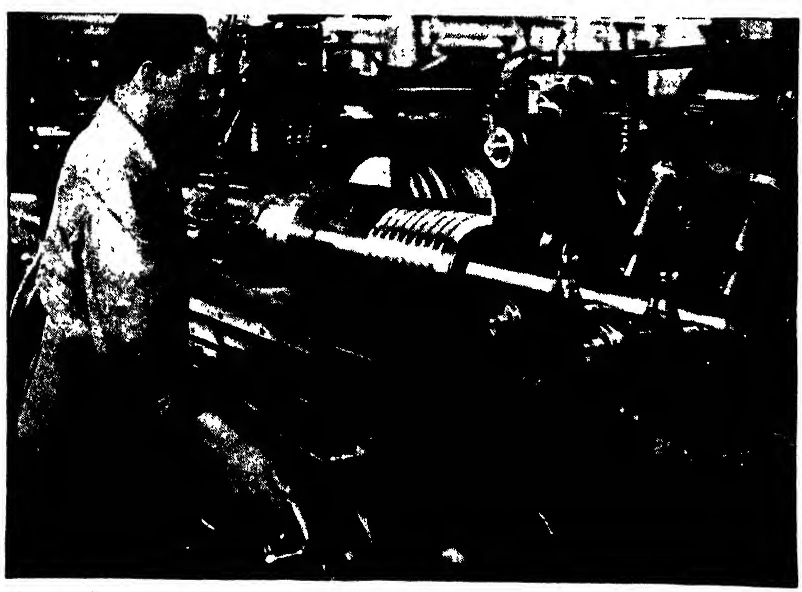


Fig. 24-2. Principles of Gage-matic Operation.

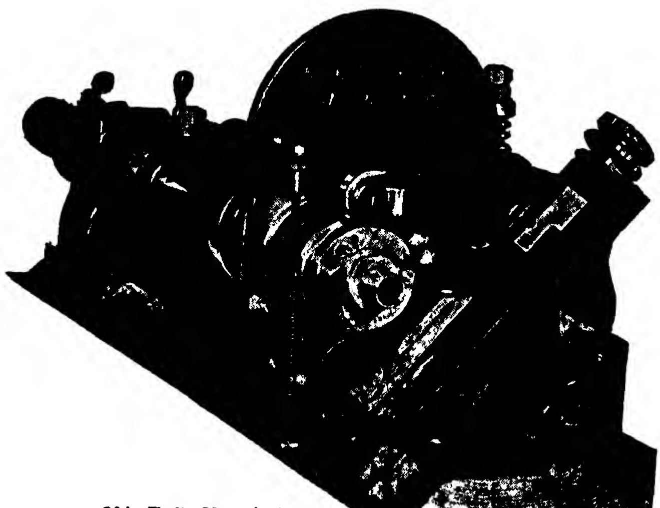


Jones & Lamson Mach. Co.

Fig. 24-3. Automatic Thread Grinding Machine.

With the exception of work loading, the machine may be automatically operated and will grind external threads, internal threads, taper threads and annular grooves.

368. Fig. 24-4 shows a **cam grinding attachment** that may be mounted on practically all standard makes of cylindrical plain and universal grinding machines. The unit consists of two trunnion brackets which are attached to the bed of a cylindrical grinder. A body or cradle carries a headstock and footstock, between which the cam to be ground is supported. A master cam is fastened to one end of the headstock spindle and actuates



Ohio Units Manufacturers

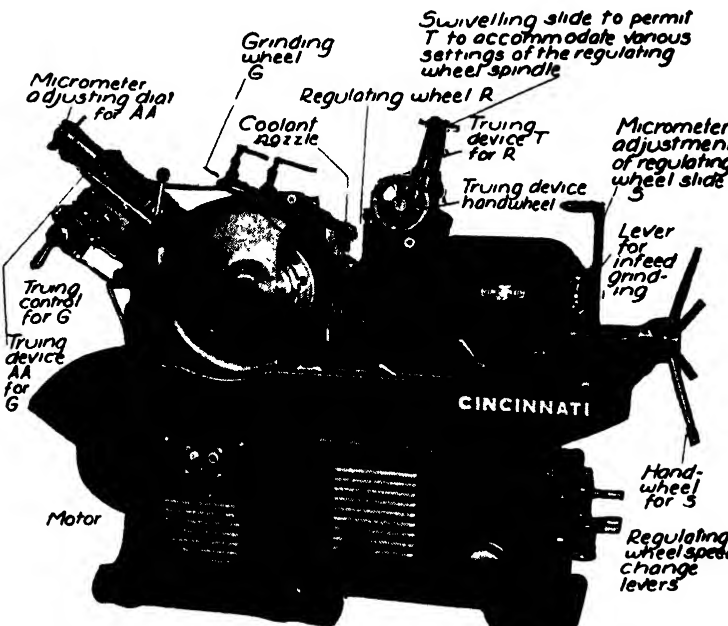
Fig. 24-4. Cam Grinding Attachment (the Wooden Block Represents a Grinding Machine Bed).

a rocker arm which moves the entire cradle about the axis of the trunnions in the trunnion brackets. This causes the work to move toward and away from the grinding wheel as the headstock spindle of the attachment rotates. The attachment can be used for grinding face cams, oval and out-of-round pistons, and similar parts in large and small quantities.

369. Centerless grinding is extensively used in mass-production operations. The process is generally a continuous one, eliminating the time required for loading and removing work, centering work, and adjusting the grinding wheel for successive cuts, all of which is necessary in the center-type grinder.

Fig. 24-5 shows a **centerless grinding machine** for finishing cylindrical bars. The operating principle of this machine is illustrated in Fig.

24-6. The cutting pressure of the **grinding wheel** G keeps the work W in contact with the **work rest blade** B and the regulating wheel R. The rotation of the **regulating wheel** causes the work to rotate at a constant peripheral speed, and the *inclination* of the regulating wheel axis moves the work from the front to the rear of the machine. The magnitude of this traversing motion is dependent upon the inclination of the regulating wheel, as well as upon its speed which varies from 50 to 200 feet per minute. The grinding wheel speed is about 6000 feet per minute.



Cincinnati Grinders, Inc.

FIG. 24-5. Centerless Grinding Machine.

There are three possible positions of wheel and work axes. Fig. 24-6 shows the conventional *above-center* position of the work axes as referred to the line connecting the centers of the grinding and regulating wheels. Work which is not perfectly cylindrical, on account of previous hardening operations or from any other cause, is generally ground in this position since the maximum corrective "rounding-up" action is thereby obtained.

Fig. 24-7 shows *below-center* placement of the work, required only when the work is not straight because of previous heat-treating operations or because it has been improperly straightened before being sent to the centerless grinding machine. Fig. 24-8 shows the *centers-in-line* position.

Work ground in this position will be of constant diameter, though not necessarily circular.

370. In the foregoing, **through-feed grinding** has been discussed. Parts such as bolts or flanged bushings cannot be ground in this manner, however, as the projecting heads or flanges prevent the work from completely traversing the wheels. For work of this character, the work rest is clamped to the slide that carries the regulating wheel, and the slide is moved away from the grinding wheel to allow the work to be placed in position on the rest. The slide carrying the work, work rest and regulating wheel is then returned to the grinding position by moving it to the left against a stop; the work is then ground and the slide withdrawn to remove

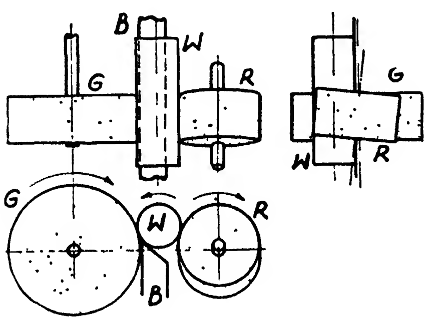


FIG. 24-6. Centerless Grinding Principles.

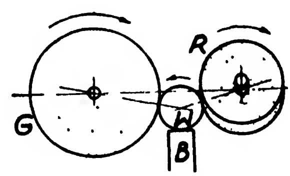


FIG. 24-7. Below-center Grinding.

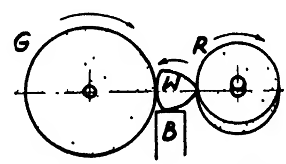


FIG. 24-8. Centers-in-line Grinding.

the work and to insert another part. This is known as the **infeed method** of centerless grinding and is illustrated in Fig. 24-9. Large work is manually positioned, but work of small and medium size is mechanically or automatically placed in position, when possible, by employing a parts magazine or a hopper and feeding the parts to position through a chute. In this method, the regulating wheel has just enough axial inclination to keep the work against the workstop shown.

Fig. 24-10 illustrates the grinding of the outer surface of a faucet pipe by the **infeed method,** using a formed grinding wheel and two regulating wheels on the same spindle. The regulating wheel axis has no inclination and is employed only to support the work and to rotate it at a constant peripheral speed. The grinding process is not primarily planned for any great precision of the surface, but to provide a smooth finished surface for plating.

Fig. 24-11 shows a bicycle hub being ground to provide a smooth surface for plating. The clearance between the multiple grinding wheel sections is ample to allow the hub flanges to drop in without interference in loading, and the grinding wheel is then subjected to mechanically-actuated axial reciprocation to permit grinding both sides of the flanges as well as the outer periphery of the hub. Yielding end stops *S* are employed so that only enough material is removed to obtain a smooth surface on the part.

Fig. 24-12 illustrates the centerless grinding method of **grinding true spheres.** The spheres are placed between formed grinding and regulating wheels, the work being positioned by a vertical infeed process.

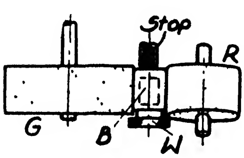


Fig. 24-9. Infeed Grinding.

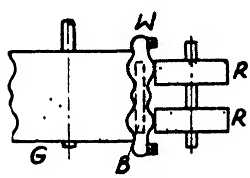


Fig. 24-10. Centerless Form Grinding.

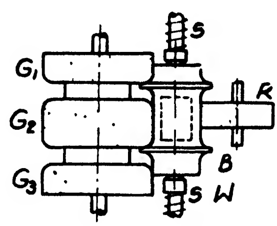


Fig. 24-11. Reciprocating Centerless Grinding.

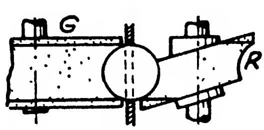


Fig. 24-12. Spherical Grinding.

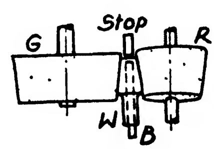


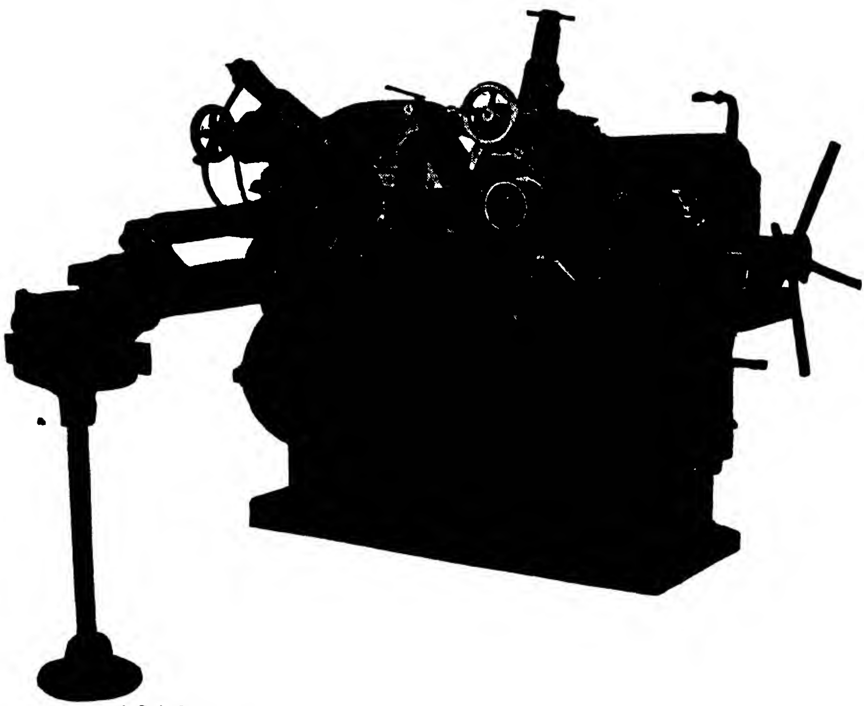
Fig. 24-13 End Feed Grinding.

To produce a true sphere the work must have a continually changing axis of rotation. This is accomplished by using the special regulating wheel shown, in which the wheel is mounted on a collet which is at an angle to the wheel axis, the wheel axis being parallel to the grinding wheel axis. Spheres made of materials such as hardened steel, monel metal, bakelite, glass and hard rubber, from $\frac{13}{16}''$ to $9''$ diameter, have been successfully ground by this method.

Fig. 24-13 illustrates an **in-feed method** of grinding in which the work is fed **axially,** as in through-feed grinding, to the stop shown. The parts are inserted and removed from the front of the machine. This method is used principally on tapered work such as twist drill and reamer shanks.

Of the methods discussed, through-feed grinding generally provides a higher production rate, and parts should be designed if possible, to permit the application of this method.

371. Figs. 24-15 to 24-20 illustrate the latest development in centerless grinding, an **internal centerless grinding machine.** Fig. 24-15 shows the essential elements of a completely automatic set-up for grinding the inner periphery of short hollow cylinders. The work is supported on



Cincinnati Grinders, Inc.

FIG. 24-14. Grinding the End of an Automotive Rear Axle Housing, Using an Outboard Roller Support for One End of the Work.

a supporting roll *O*, and is pressed against the regulating wheel *R* by the pressure of roller *P*. The reciprocation of the grinding wheel *G* is axial, parallel to the axis of the rotating work, and the arrows show the directions of rotation of the grinding wheel, regulating wheel and work. The rollers *P* and *O* also rotate on the studs on which they are mounted. Fig. 24-16 shows the first stage of removing the work *V*; the roll *P* has swung back and the loading arm *A* is lifting up the work, rolling it on the surface of the regulating wheel, the grinding wheel *G* having been previously withdrawn from the inside of the work. Fig. 24-17 shows the finished part just before

being dumped into the unloading chute N. Fig. 24-18 shows the loading arm partly back in position, while the work stop S has been lifted to permit a new part W to fall or roll into position. As soon as the work is in position, the work stop S drops back into position and thereby prevents more than

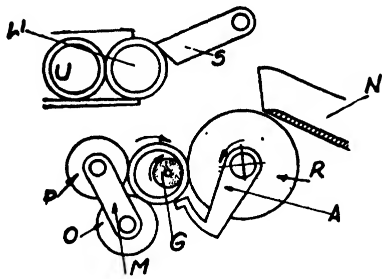


Fig. 24-15. Internal Centerless Grinding.

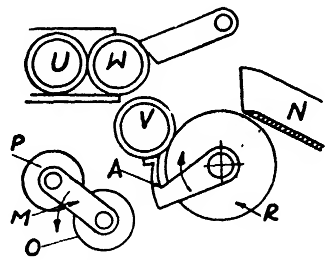


Fig. 24-16. First Unloading Stage.

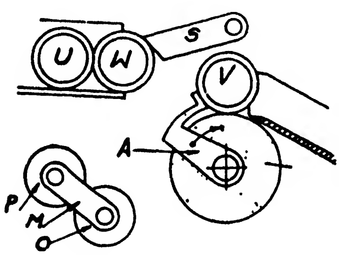


Fig. 24-17. Second Unloading Stage.

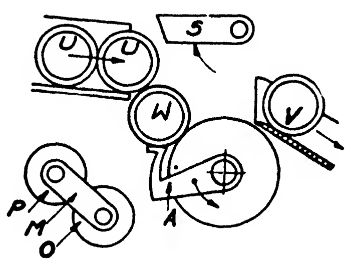


Fig. 24-18. First Loading Stage.

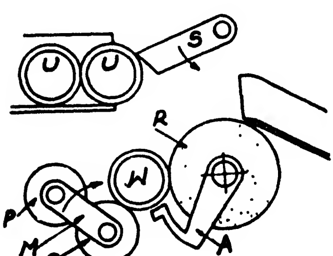


Fig. 24-19. Second Loading Stage.

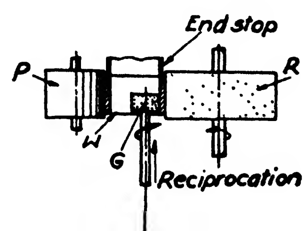
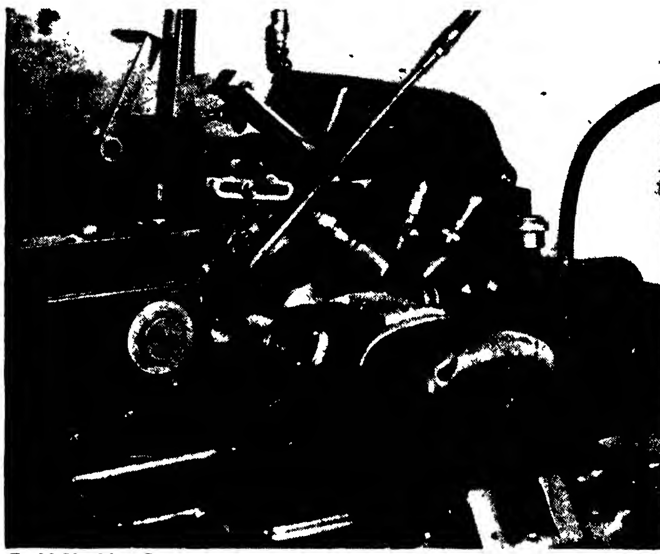


Fig. 24-20. Plan View of Internal Centerless Grinding.

one part from dropping down at one time. The loading arm A continues its return to its original position of Fig. 24-15, illustrated in Fig. 24-19, and the pressure roll swings back into place to hold the new part against R. The grinding wheel then enters the hole and grinds the inner surface.

By employing internal centerless grinding, concentricity of inner and outer surfaces is assured since the entire wall thickness has to pass between G and R, as shown in Fig. 24-15. Obviously, the outer periphery of the work must be truly cylindrical to insure the same result for the inner periphery. Fig. 24-20 illustrates a plan view of the principal elements of this machine. There are two principal forms of the machine: the **On-center type** illustrated in the figures, and the **Hi-center type** in which the work and grinding wheel axes are above the regulating wheel



Heald Machine Co.

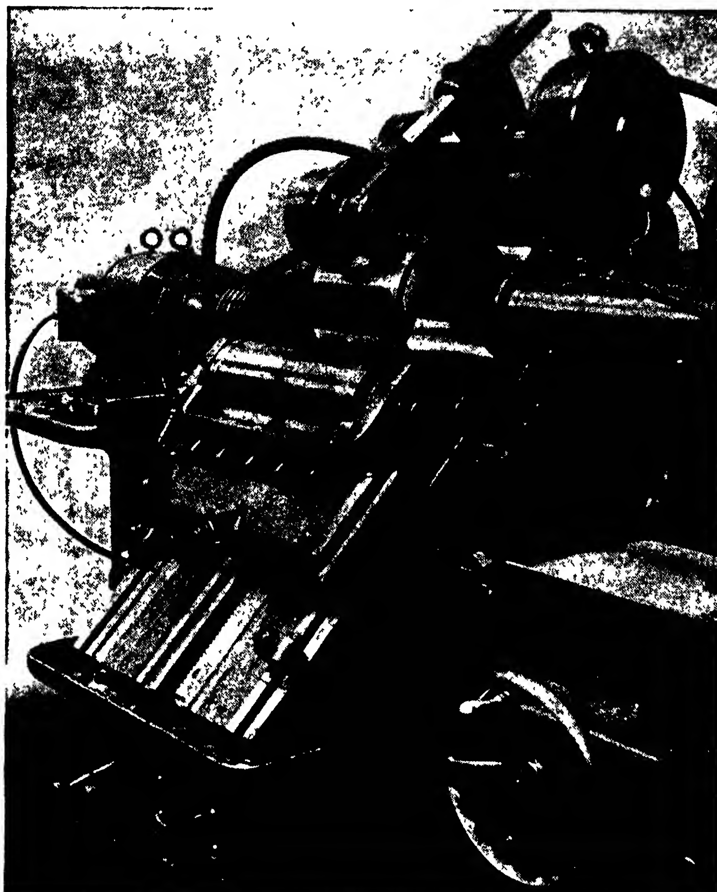
FIG. 24-21. Internal Centerless Grinding Eleven Aetna Thrust Bearings at One Time.

axis. The first type is used for thin-walled work where there is danger of distorting the part unless the centers of G and R are in line. The second type is generally employed for grinding multi-diameter work to closer tolerances than is possible with the On-center type. The entire machine is hydraulically operated and actuated, causing the grinding wheel to enter the work, rough-grind it, true the wheel, finish-grind the work, and return to a position such that it will not strike the new part on entering.

Loading and unloading arrangements may also be applied to external centerless grinders.

372. There are three representative processes of surface finishing that are extensively used in the mass-production system in industry: **honing, mechanical lapping, and Superfinishing.** All three make use of commercial abrasives in some form: honing and lapping produce dimen-

sional changes as well as surface refinement; Superfinishing is principally concerned with the removal of amorphous metal from previous machining operations. All three processes lend themselves to high production rates at costs which are extremely reasonable when the dimensional accuracy and the character of the surface finish are considered.

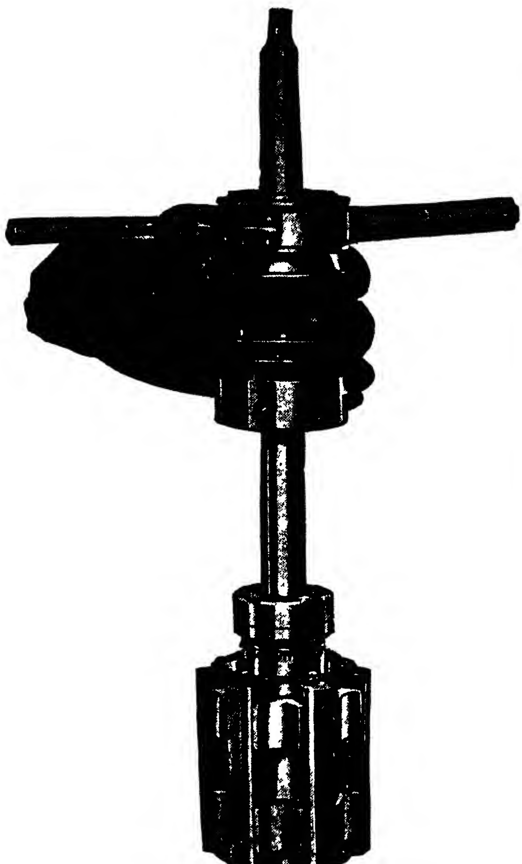


Heald Machine Co.

FIG. 24-22. Internal Centerless Grinder Finishing the Bore of Roller Bearing Races.

373. **Honing** is a wet cutting process which involves the mechanical application of bonded abrasives to the surfaces of cylindrical holes, and in some instances, to the surface of cylindrical parts. The honing tool has a body which carries several long and relatively narrow stones of artificial abrasive material mounted in metal holders. These holders are carried in

shoes which have free radial movement within the established limits, and which are arranged to be expanded by different methods. In the **brake type of hone** illustrated in Fig. 24-23, the stones are radially expanded by pushing upward on the lever at the left. This type of hone is



Micromatic Hone Corp.

Fig. 24-23. Brake Type, Manually-adjusted Mechanically-actuated Hone.

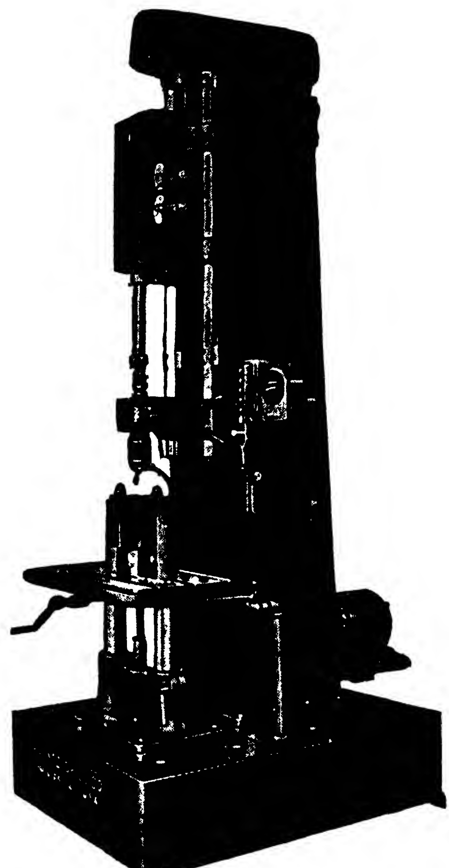
Micromatic Hone Corp.

Fig. 24-24. Three-finger Automatic Hone.

manually adjusted by an operator as the operation proceeds and is therefore used for low production rates. The hone of Fig. 24-24 has three fingers or bell cranks which move longitudinally in a steel sleeve above the stones, and which maintain a spring pressure on the stones against the walls of the cylinder or hole. The holder quickly expands the hone as the tool enters the hole, gradually feeds the stones out radially until a positive

size stop has been reached, and retracts the stones into the body before the hone is withdrawn. The **three-finger hone** is used for mass-production honing, particularly for finish-honing operations. Hydraulically-actuated hones are also extensively used, particularly for rough-honing operations.

Internal honing is accomplished by simultaneous rotation and reversing reciprocation of the hone under pressure in the bore. This motion causes the hone to travel in a widely-angled helical path. The particles of abrasive on the hone do not cut uniform helices or follow previous paths and the stones are self-cleaning. **Honing speeds for cast iron** bores range from 200 to 250 peripheral feet per minute of rotation, and from 50 to 75 lineal feet per minute of reciprocation. **For steel,** rotary surface speeds range from 150 to 200 feet per minute; the rate of reciprocation is about 40 feet per minute. V-type 8-cylinder motor blocks are honed at an average rate of 90 blocks or 720 cylinders per hour. Crankshaft bearing holes in connecting rods are honed 4 at a time at a rate of 300 per hour while maintaining limits of .0003″.

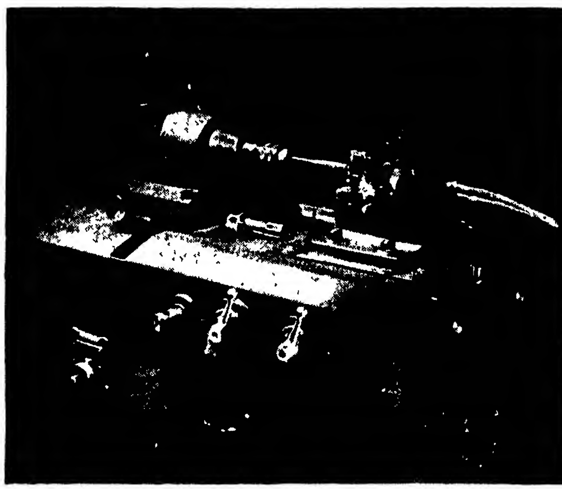


Barnes Drill Co.

FIG. 24-25. Hydraulically-reciprocated Honing Machine.

Fig. 24-25 shows a **vertical hydraulically-reciprocated honing machine** with a standard hone travel of 16″. The machine is shown with a temporary setup for honing the bore of a small bushing. The work is supported on box parallels and held by clamp straps on a horizontal table which is guided by two columns that may be clamped at any point. The table may be elevated to position by the telescoping screw between the guide columns. The machine is equipped with an electric timing device which determines the duration of the honing cycle by the elapsed number of minutes or seconds. For mass-production operations suitable fixtures are em-

ployed to hold and align the parts to be honed. Fig. 24-26 illustrates a **horizontal-spindle honing machine** for producing by honing a high degree of surface smoothness termed Microfinish. The hone is carried by the spindle, which is driven through vee belts by the motor on the spindle head, and has a combined rotating-reciprocating motion. The work table at the right, which has a work fixture mounted on it, is hydraulically actuated, moves up automatically to its working position, and is then slowly reciprocated through its adjustable pre-determined working stroke. The machine is shown honing the bore of an airplane-engine valve tappet guide



Micromatic Hone Corp.

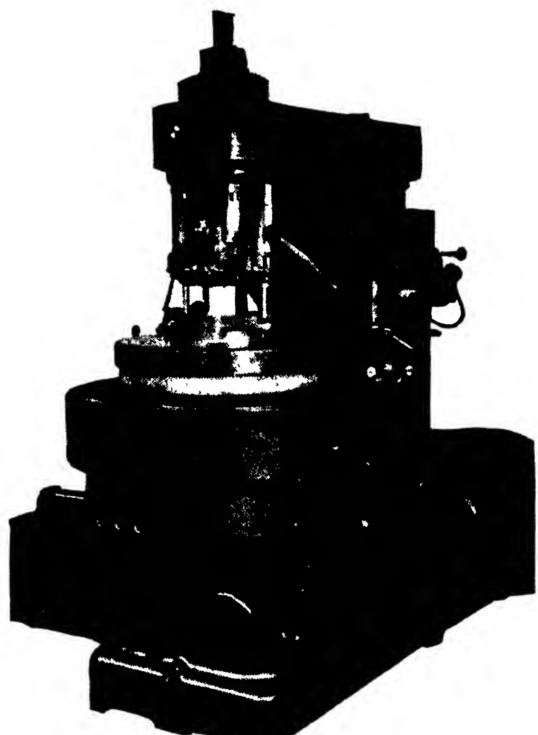
FIG. 24-26. Hydraulically-actuated Honing Machine for Bores 1/4" to 2" Diameter Up to 6" Long.

(a finished part is shown on the bed of the machine). In this operation, the bore accuracy is held within .0002" for roundness and straightness, and approximately .001" of stock on the diameter is removed from a ground finish. **Double-spindle machines** of this type may also be obtained.

Cylindrical holes with keyways or other openings can be finished by honing if the width of the stones is sufficient to "bridge" the opening in the surface of the bore. Blind holes can be honed by carefully controlling the termination of the honing stroke, and by permitting the hone to make a few revolutions in the extreme bottom position before the normal stroke begins. For *through* horizontal honing, the honing tool is generally piloted at one or both ends of the hole by pilots on the tool and bushings in the fixture.

374. Mechanical lapping is analogous to hand lapping and is often the final stock-removing operation for sizing and finishing gages and other commercial precision parts. Three types of lapping media are ordinarily used: bonded abrasives for the usual run of commercial precision work; metal laps and loose abrasive mixed with a lubricant for gage manufacture; and abrasive paper or cloth, for crankshaft lapping.

Fig. 24-27 illustrates a **vertical lapping machine** in which bonded abrasive wheels are mounted on vertical spindles and the work is driven in a horizontal plane between the upper and lower laps. The laps rotate in opposite directions, and the lower lap is carried on a tubular spindle through which the work holder shaft extends. The upper lap is carried on a counterweighted spindle which is raised and lowered by two hydraulic pistons. The lapping pressure is established by a pressure regulating mechanism and an adjustable micrometer stop limits the position to which the upper lap is fed. Available pressures range from 20 to 100 pounds per square inch.



Norton Company

Fgi. 24-27. Hyprolap, or Vertical Lapping Machine.

Fig. 24-28 illustrates the arrangement of the laps and the work-holder, or cage, for **lapping** the outer **cylindrical surface** of wrist pins. The work-holder has a rotary-oscillating motion similar to that used by a toolmaker in hand lapping. The work-holder shown in Fig. 24-28 has a central spider S with tangential pins A whose diameter is about 1/16″ less than the bore of the work W. Four of these pins extend past the work and carry a retaining ring R to keep the work in place. The work is free to revolve on the pins and has about 1/8″ end play. This type of work-holder permits rapid loading and unloading

but two spiders are usually provided for each machine so that the spider can be lifted on and off the machine completely loaded and thereby eliminate practically all the loading time while the machine is in operation. Lubricant consisting of soap and water is pumped to the work and wheels.

Solid cylindrical and flat work is carried in simple plate work-holders illustrated in Fig. 24-29. The work-holder for the flat discs shown is provided with finger spaces so that the parts may be readily removed when the upper lap is lifted. These types of work-holders remain on the machine and are so arranged that they touch neither lap, but serve only to guide the work as the work-holder rotates and oscillates. The laps are 24″ in diameter and the upper lap rotates at about 100 r.p.m. The lower lap rotates in the opposite direction at 113 r.p.m. Silicon carbide and aluminum oxide lapping wheels are used for rough lapping, and silicon carbide shellac bonded wheels for finish lapping. Production rates of 500 wrist pins per hour are easily maintained to limits of .0001″ for straightness and roundness.

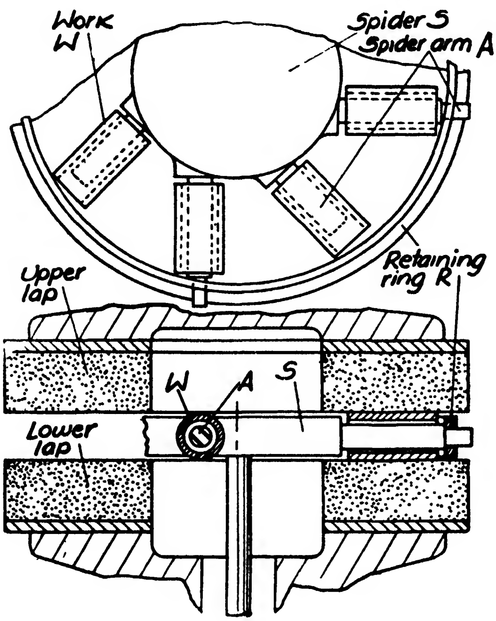


FIG. 24-28. Vertical Lapping Machine Principles.

The laps are trued by an hydraulically-actuated device which carries two independently adjustable diamonds. The device can be set so that the lap faces will be parallel and also perpendicular to their axes of rotation.

375. For **gage lapping,** two **lapping discs** of soft close-grained cast iron are used instead of the abrasive wheels. The upper lap remains stationary and the lower lap rotates at about 60 r.p.m. Aluminum oxide abrasive, mixed with kerosene and lard oil, is applied by means of a brush to the work which is carried in rotating-oscillating work-holders similar to Fig. 24-29. A production rate of 60 to 80 gages per hour, with a good commercial finish, may be obtained.

For satisfactory precision lapping, the lap surfaces must be true planes. The process of **generating true planes** is very similar to the process

of originating straight edges described in Chapter 4. Three laps are hand-scraped to a surface plate and one of the laps is then fastened to the table of a drill press. The second lap is placed on the first with a film of abrasive and oil between the contact surfaces. By means of a short-throw crank attached to the drill spindle, the upper lap is made to move in a circular eccentric path across the lower lap, which also causes the upper lap to rotate slowly about its own axis. This motion of the upper lap reduces the faces of both laps until they match. The first lap is then worked with the third,

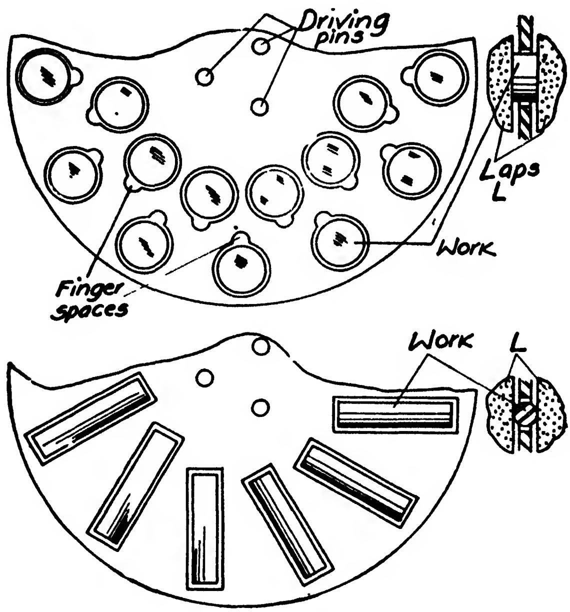
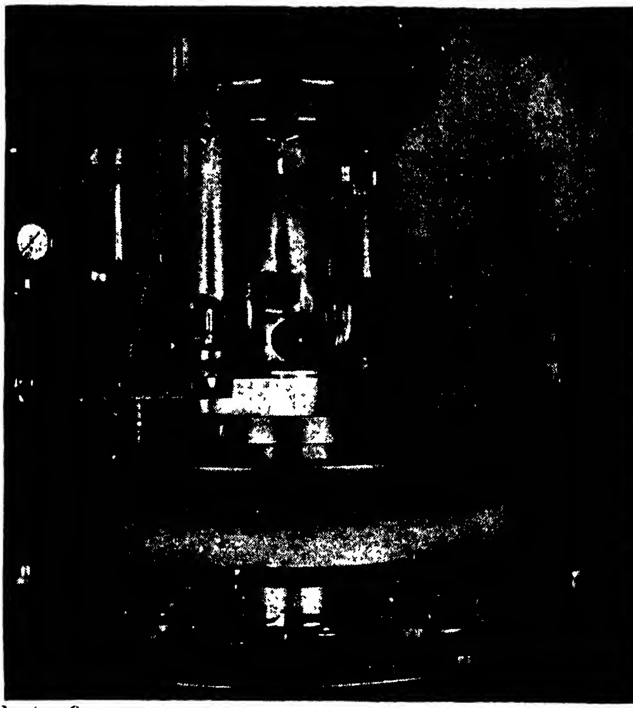


Fig. 24-29. Work Holders for Flat and Cylindrical Work.

and then the second with the third, continuing until a true surface has been attained. Such laps may be used without any additional abrasive for finishing operations since the lap surface retains enough abrasive for this purpose.

376. Cylindrical work may also be lapped by employing a **centerless lapping machine** which is similar in principle to the centerless grinding machine previously described. The principal field of application of this machine is in improving the size and finish of cylindrical work that has no interfering shoulders, and which has previously been ground to a good commercial finish and tolerance. Work of this type is lapped by the **through-feed method. In-feed lapping** for shoulder work can also be

handled on this machine. The centerless lapping machine differs from the centerless grinder in one important mechanical respect; both the lapping wheel and the regulating wheel brackets can be swivelled in a vertical plane. Ordinarily the regulating wheel is set to a positive feeding angle of from one to three degrees, depending upon the production and feeding requirements, while the lapping wheel is set to a negative angle of 4°. Both wheels



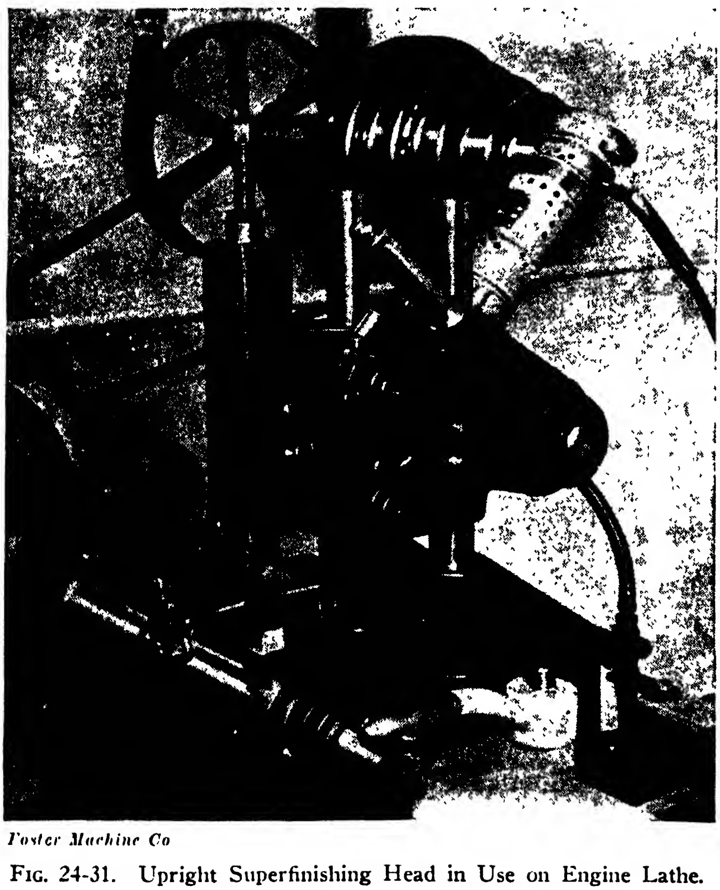
Norton Company

FIG. 24-30. Raising the Upper Lap of the Hyprolap, with Work in Position for Flat Lapping.

therefore assume hyperboloidal shapes when trued, and contact the work at an angle to its axis as opposed to the axial line of contact of the grinding wheel. This difference in contact assists in rapidly eliminating marks and scratches from previous grinding operations.

377. Superfinishing, developed by the Chrysler Corporation, is an abrasive process for removing smear metal, scratches and ridges produced by machining and grinding operations, and other surface irregularities, from parts that are to have a highly finished surface. The process resembles lapping in that a lubricated abrasive stone is applied to the surface at com-

paratively low speeds and light pressures. Fig. 24-31 shows an **upright type superfinishing head** whose base is attached to the cross slide of an engine lathe. The base supports two vertical cylindrical guides on which the head proper may be manually adjusted to the work by the hand lever shown. The abrasive stone is carried in a vertical slide which is subjected



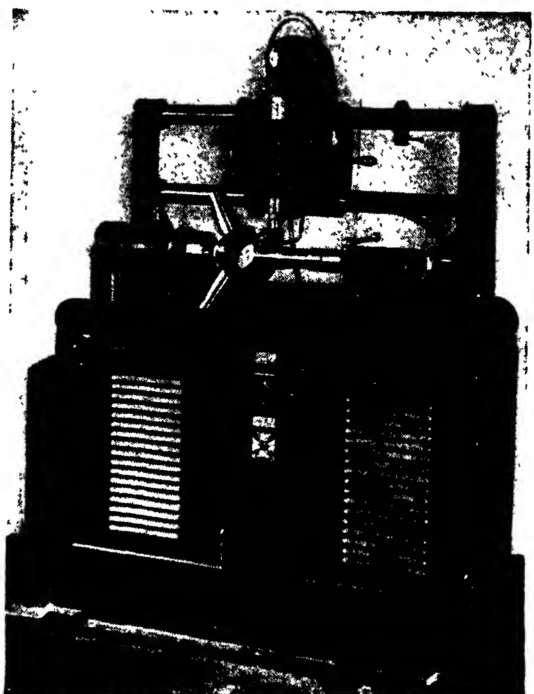
Foster Machine Co

Fig. 24-31. Upright Superfinishing Head in Use on Engine Lathe.

to the action of a spring for applying pressure to the stone. The stone pressure may be regulated to suit the requirements of the work by turning the screw at the top of the slideway.

In operation, the work rotates between centers at a surface speed of about 30 feet per minute for roughing to from 70 to 100 feet per minute for finishing operations. The stone is moved axially along the surface of the work by using the coarsest feed of the lathe carriage. As the carriage

feeds, the stone is subjected to short, frequent, axial oscillations by the motor shown at the rear of the Superfinishing head. For average work, a spring pressure of from 12 to 20 pounds per square inch is employed, using kerosene as a lubricant. The **cutting action cycle** is as follows: when the stone is first applied to the work, it comes in contact with the peaks of the minute serrations with a high unit pressure because of the

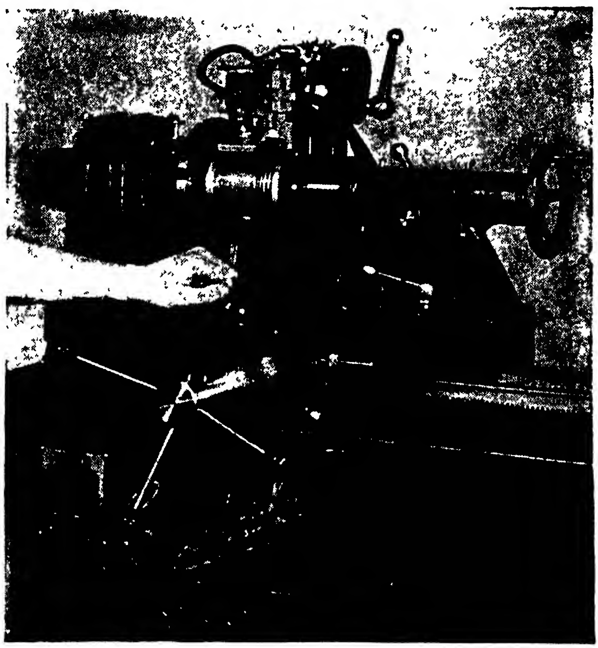


Foster Machine Co.

FIG. 24-32. Superfinishing the Bearing Surfaces of the Spokes of an Airplane Propeller Hub on a General-purpose Machine.

small area of contact, causing the abrasive to tear out comparatively large metal particles and effecting a comparatively large loss of abrasive particles. These particles are immediately washed away by the lubricant. This tearing tendency is rapidly reduced as the serrations wear flat, and the metal particles finally become so small that they immediately oxidize and begin to fill the pores of the stone. This metallic oxide is in itself a polishing agent and contributes to the finishing action. When the combination of improvement in surface condition of the work and the dulling and glazing of the stone face has reached a certain point, the decrease in unit pressure allows the

lubricant to prevent further contact between the stone and the work. The surfaces in contact have such a comparatively large area, and consequently such a low unit of pressure, that the lubricant is drawn between the surfaces and forms an oil film as in perfectly lubricated bearings. For repetitive work the process therefore ceases at the same point in each cycle, and surfaces of like degrees of finish are obtained on duplicate parts. After a Superfinished part is removed and an unfinished part is substituted, the



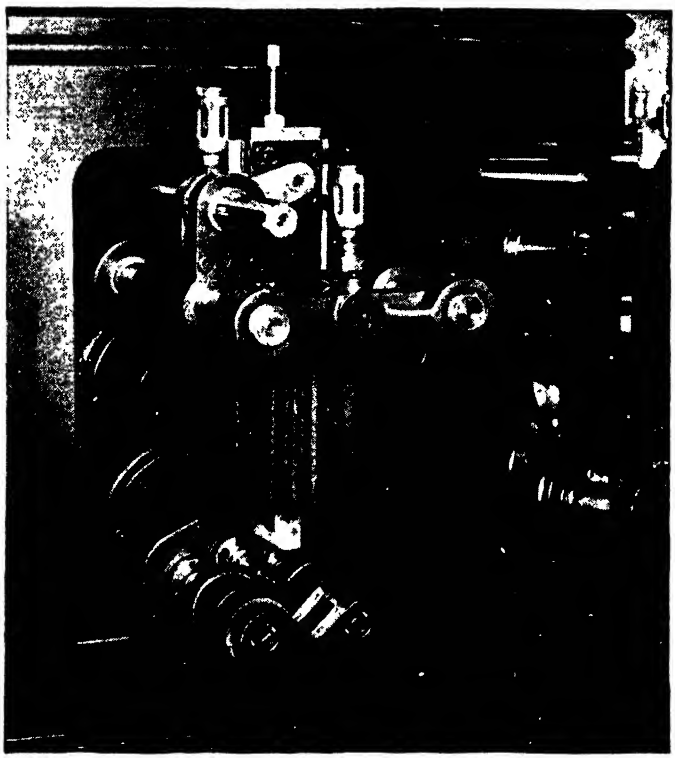
Ohio Units Manufacturers

FIG. 24-33. Universal Superfinishing Machine Using Dual Stones on an Automotive Piston.

stone is automatically dressed sharp by its application to the peaks of the serrations on the new part and the cycle is repeated.

378. Fig. 24-32 illustrates a **general purpose Superfinishing machine** which is equipped with a rotating spindle headstock and a tailstock, both of which are similar to, although somewhat simpler in detail than, the corresponding parts of an engine lathe. The Superfinishing head is supported by and moves on two horizontal bars as illustrated. The motor at the top of the head provides power for both the axial traverse and the oscillating motion of the stone. In this machine, work can be carried between centers as illustrated or it can be held in a collet in the headstock. **Fig. 24-33 shows**

another **machine for Superfinishing pistons.** It should be noted that only pistons of full skirt type without relief can be handled with this equipment. The carriage of the machine is traversed by hand between limits that are set by the adjustable screw and nut. Crankshaft and crankpin bearings may also be Superfinished on this machine. An auxiliary member is used for this type of work, in conjunction with the oscillating head, so



Foster Machine Co.

FIG. 24-34. Centerless Superfinishing.

that the head may freely follow the throw of the crankpin as the shaft revolves about the axis of the crankshaft bearings. Flat surfaces such as clutch faces may be Superfinished as readily as cylindrical surfaces.

Fig. 24-34 shows a **semi-automatic machine for Superfinishing** the cylindrical shanks of valve tappets. The machine has 12 operating stations and the operator loads and unloads the work. The work is supported on two rollers and is driven by a collet chuck at its inner end. A production rate of 750 parts per hour is attained with this machine.

379. The bond hardness of the superfinishing stones is the most important factor in the process; so important, in fact, that variations in hardness that might be neglected in grinding operations have a material effect on the efficacy of the Superfinishing operation. To overcome this difficulty, the Foster Machine Company devised the Foster-Rockwell test for the bond hardness of abrasives. The test uses the Rockwell Hardness Tester—combination *H*—for making penetration tests on the abrasive stones. These tests give hardness readings which are found to be more valid, in a number of instances, than the wheel grades given by abrasive manufacturers. At present the test is confined to stones between 320 and 1000 grain size.

CHAPTER 25

SPECIALIZED MASS-PRODUCTION PROCESSES

380. There are a variety of **miscellaneous operations and processes** that are difficult to classify in relation to any of the procedures previously described. Some of these are highly specialized although important; others represent a combination of so many processes that a summary of this nature is almost inevitable. In this chapter we shall describe several unusual operations, give a brief survey of a few interesting manufacturing processes, and close with a description of an automatic machine designed for a specific series of operations.

381. Fig. 25-1 illustrates a lathe set up with a **cutter-relieving attachment** for machining the **eccentric relief** necessary for free cutting on the **form-type cutter** of Fig. 8-9. The attachment consists of a splined shaft which is mounted at the rear of the lathe. The shaft is connected to the spindle by suitable change gearing, and carries a cam which acts on the compound rest causing it to move towards the axis of the work as the spindle makes a part of a revolution. The action of the cutter and set up-shown in Fig. 25-1 is diagrammatically illustrated in Fig. 25-2. As the mandrel on which the cutter to be relieved is mounted rotates through the angle shown, the relieving tool moves in and machines the relief on the tooth. Each tooth of the cutter is relieved in a separate operation but the same amount is taken from each tooth. The attachment can be used for end and internal relief as well as for the external radial relief illustrated.

382. Fig. 25-3 shows a completely automatic precision machine for **tapping hexagonal nuts.** The tap used in this machine is illustrated in Fig. 25-4 which also shows another tap full of nuts. The nut blanks are dumped into a hopper shown at the right in Fig. 25-3, and are fed into a chute by a slowly rotating vane wheel. Each successive blank drops into a recess in a rotating spindle, and the non-rotating tap is moved into the hole in the nut blank at a definite rate to insure threads of the correct pitch. The tap is held in position by the nuts on the shank and each nut that is threaded moves up the shank and forces off a nut at the other end.

Nuts may also be tapped by using a tap with a **long straight shank.** In this case it is necessary to stop the machine and remove and strip the tap of nuts when the shank is full. Another type of machine uses a tap with a long shank which is bent to an angle of 90°. In this machine, which is used for nuts of ordinary accuracy, the tap rotates and the nuts

Ledge & Shipley Machine Tool Co.

Fig. 25-1. Cutter-relieving Operation.

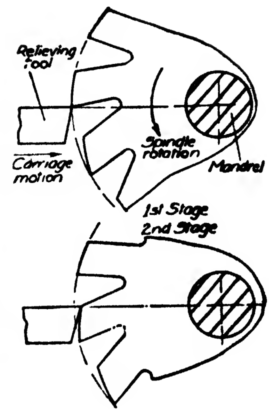


Fig. 25-2. Principle of Operation of Form-type Cutter Relieving Attachment.

National Machinery Co.

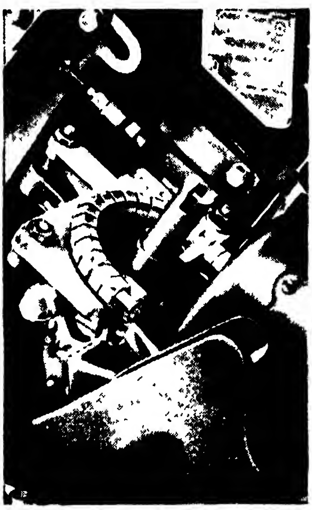
Fig. 25-3. Automatic Nut Tapping Machine.

National Machinery Co.

Fig. 25-4. Hook Tap for Nut-tapping Machine.

are fed to the tap by a plunger. The **bent-tap nut tapper** is completely automatic; the operator need only fill the hopper with nut blanks as required.

383. Fig. 25-6 shows the sequence of the principal operations in the **manufacture of taps** whose threads are ground from the solid. The first operation shows how the bar stock is cut off either on a milling machine or a power saw; and both ends of the blank are centered on a drill press or a centering machine in the second operation. In the third operation the body and shank diameters are turned and the blank is faced to length. The body of the blank is fluted in the fourth operation by using a half-round milling cutter. The end of the shank is then squared by two special form-type straddle mills; the shank is stamped with the number of the tap and the manufacturer's name in the sixth operation; and the blank is heat-treated and hardened in the seventh operation. The center holes are lapped prior to grinding the body and the flutes are ground and polished in the tenth and eleventh operations. The threads are ground from the solid blank on a thread-grinding machine in the twelfth operation and the point of the tap is chamfered in the final operation shown. None of the inspection operations are shown in this sequence.



National Machinery Co.

FIG. 25-5. Detail View of Nut Tapping Machine with Holder Removed.

384. Figs. 25-8 to 25-12 show the **operational sequence** and an **automatic machine for machining a special bushing** from special cast iron bar stock. Fig. 25-8 shows the original bar stock, as received from the foundry, and the finishing bushing. Fig. 25-9 shows the sequence of operations on an **automatic bar machine** or first-operation machine. The bar is brought against a stop in the first turret hole; the turret indexes; the central hole is drilled $\frac{1}{64}''$ undersize, and the body of the bushing turned and the shoulder faced with a box tool. The turret indexes to the third station and the bushing hole is rose-reamed to within .005″ of size. The turret indexes and the edge of the hole is chamfered by using a piloted countersink. Meanwhile, the form tool begins shaping the tapered flange and facing the shoulder of the bushing; the countersink is withdrawn before the right end of the bushing is faced. After the forming operation is com-

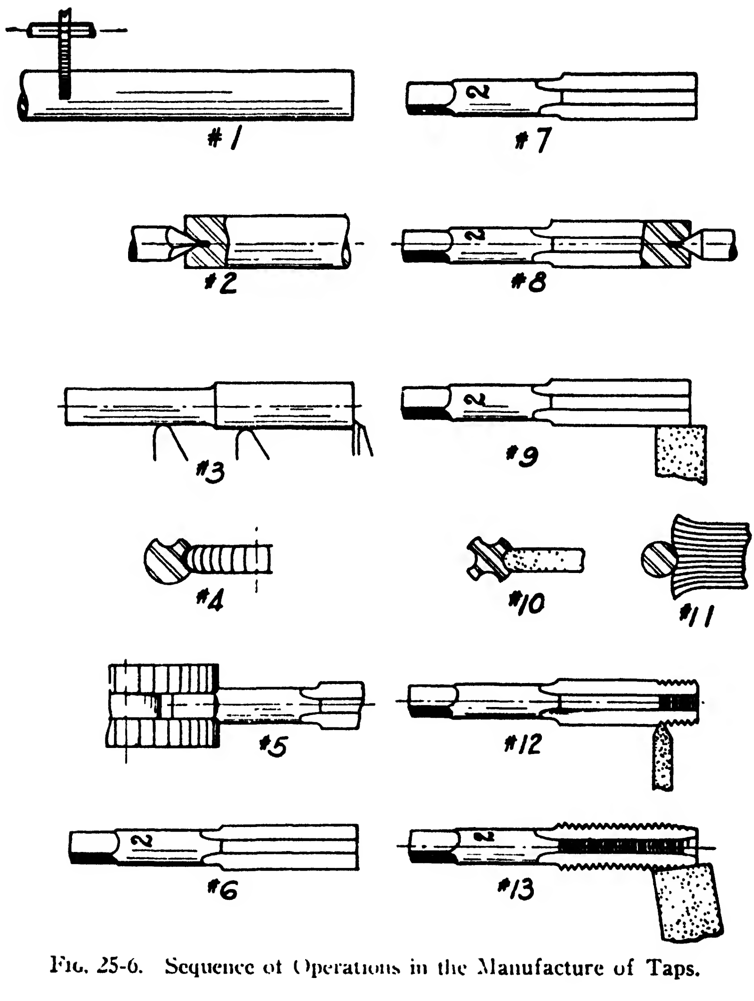
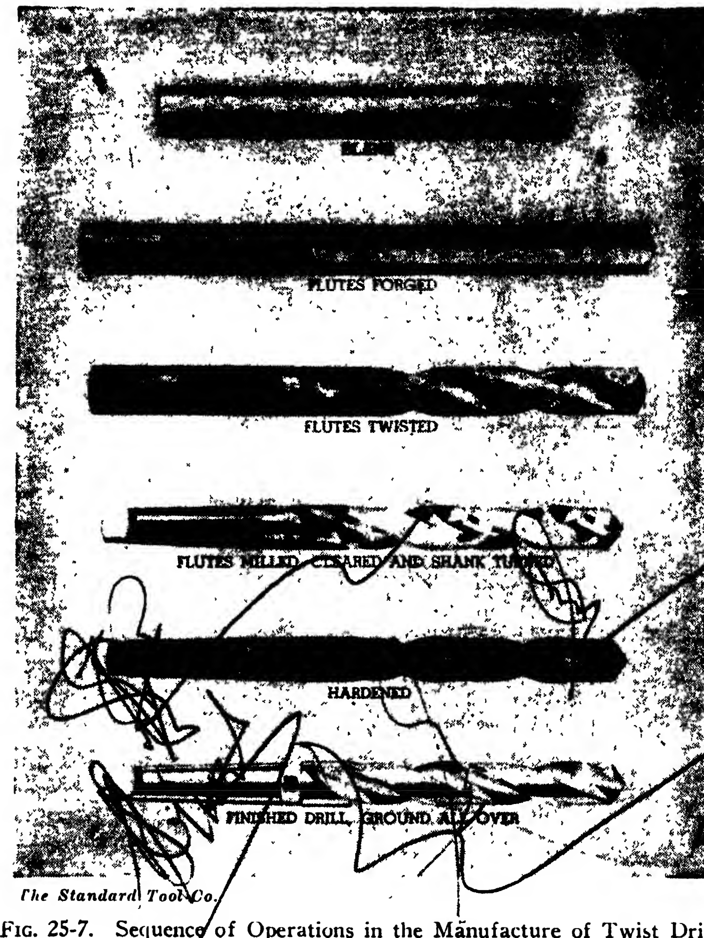


FIG. 25-6. Sequence of Operations in the Manufacture of Taps.



The Standard Tool Co.

FIG. 25-7. Sequence of Operations in the Manufacture of Twist Drills.

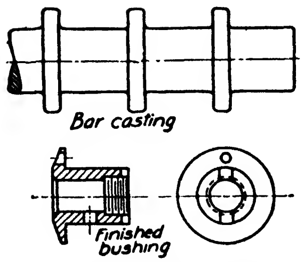


FIG. 25-8. Bar Casting and Finished Bushing.

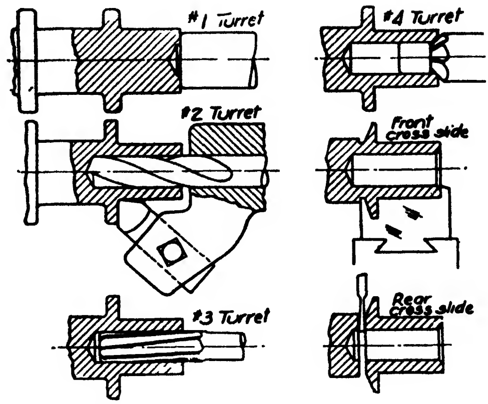


FIG. 25-9. Sequence of Operations on Automatic Bar Machine.

pleted, a cut-off tool on the other side of the cross-slide cuts off the bushing. During this period the turret indexes through its idle stations. The bar is then moved forward against the stop and the original cycle is repeated. In the second turret tool operation, the hole is drilled, to a depth somewhat greater than the finished length of the bushing to serve as a starting spot for the drilling operation on the next part, and also to eliminate the necessity of reaming to the bottom of the hole.

385. Fig. 25-12 shows a **second-operation machine** for completing the machining processes on the bushing. This machine has been specially designed for these operations, and is fully automatic except for the loading and unloading operations of the parts as received from the bar machine. The machine is illustrated in Fig. 25-11 and Fig. 25-12, and the sequence of operations is shown in Fig. 25-10. The parts are carried two in a station on a six-station turret that indexes about a horizontal axis. In Fig. 25-12 the upper station at the right is the loading and unloading station, and the upper station at the left is the station where the flange hole is drilled. The turret rotates in a counterclockwise direction, as seen in

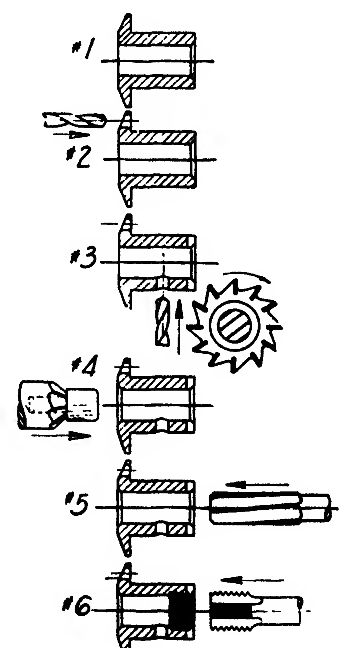


FIG. 25-10. Sequence of Operations on Automatic Bushing Machine.

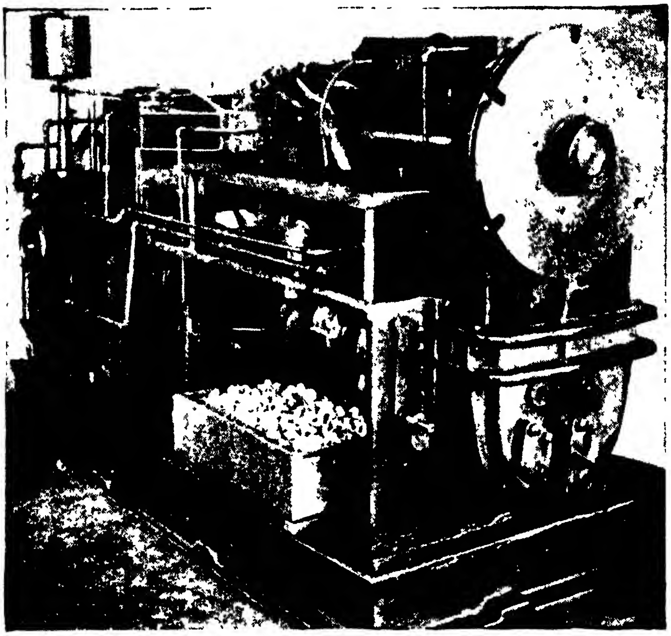


FIG. 25-11. Second-operation Machine for Bushing, Looking at the Rear of the Turret.

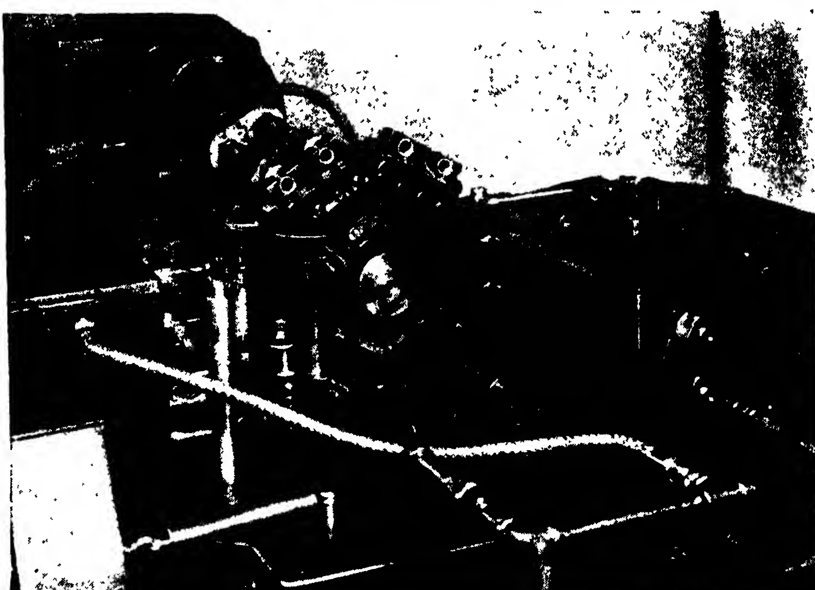


FIG. 25-12. Second-operation Machine for Bushing Seen from the Front of the Turret.

Fig. 25-12, through 60° and is locked, for every indexing operation. The station at the right is a tapping station; the tapping head moves in a dovetail slide in a vertical plane. Below and to the left of the tapping head is the reaming station. The station at the extreme left is a combined drilling and milling station; the drills, the side milling cutters, and the vertical overarm and arbor support for the cutter arbor are shown. The machine is automatically lubricated from a central pump; the oil flows through the flexible tubing

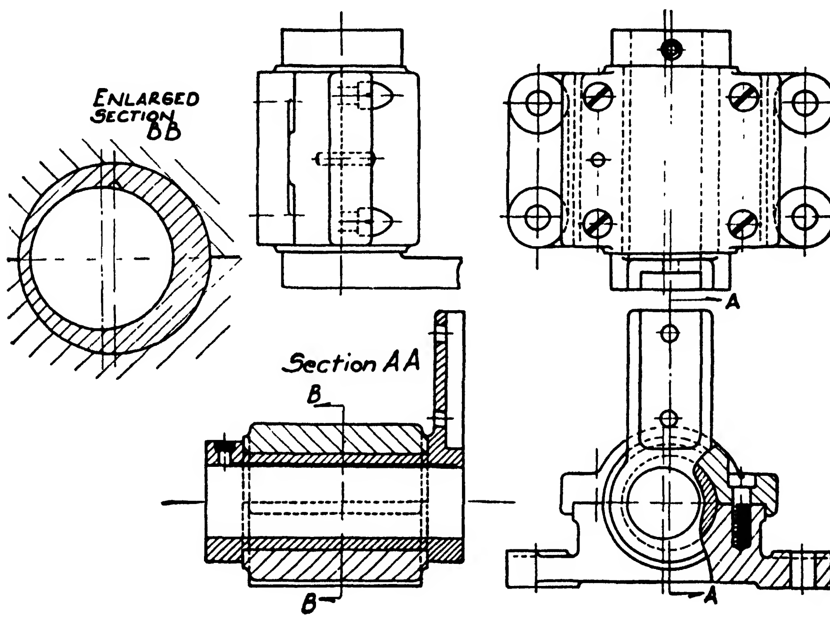


FIG. 25-13. Eccentric Bearing.

shown to the various units. Fig. 25-12 shows the machine as seen from the rear of the turret; the turret index plate and the locking plunger may be seen at the right. A steel "tote-box" filled with finished bushings rests on the bed of the machine.

Fig. 25-10 shows the sequence of operations on this machine. The first station is used for loading and unloading; the flange hole is drilled at the second station; the oil hole is drilled and the end slot is milled at the third station; the fourth station is used for chamfering or countersinking the flange end of the bore; the bore is finished by reaming with a floating reamer at the fifth station; and the bore is threaded to the proper depth by a tap

at the sixth station. Two parts are held and operated upon at each station, and two finished parts are therefore produced for every 60° index cycle of the turret. The machine has a production capacity of several hundred

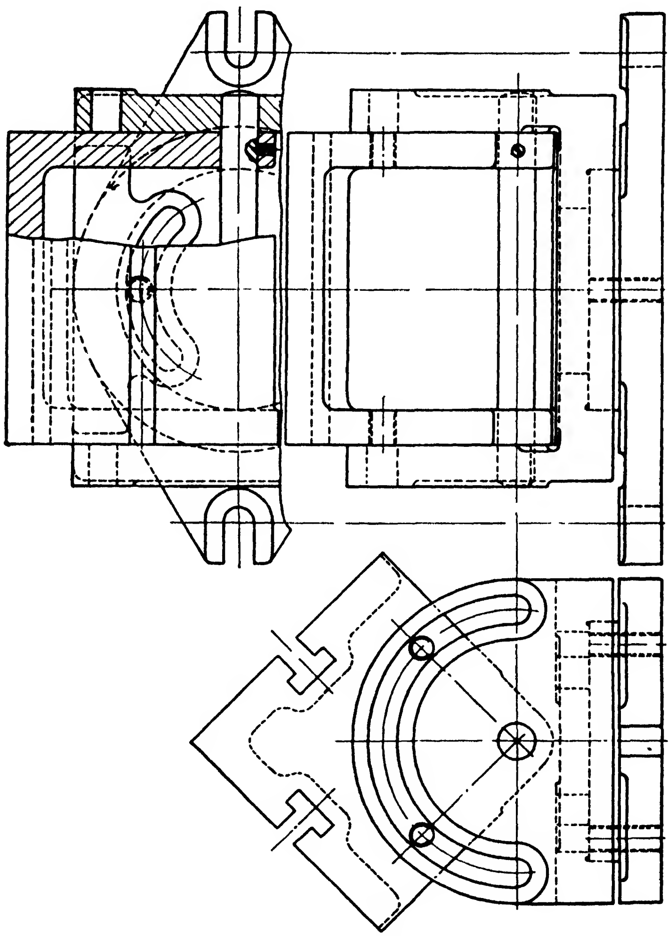


Fig. 25-14. Adjustable Angle Plate.

bushings per day and can be cared for by a comparatively unskilled operator, although tool resharpening and resetting is generally done by a skilled mechanic.

CHAPTER 26

PRODUCTION DESIGN CONSIDERATIONS

386. The design of parts, devices and machines for commercial and engineering application should be considered under two heads. The first of these, **functional design,** necessitates an analysis of such phases as adequate functional operation, sufficient strength, and resistance to wear. The other phase, **production design,** requires consideration from the standpoint of manufacturing feasibility and economy. Functional design may be studied in courses in machine, structural and equipment design; production design is based upon consideration of and experience with shop processes and practices. This phase of industrial design is unfortunately too often neglected, although it is usually a major factor in the commercial success of the product.

In many engineering organizations the functional design of a product is carefully considered at the inception of the problem, and the design is turned over to the manufacturing division *after* the desired functional results have been attained. Any alterations to facilitate production or to improve manufacturing feasibility must then be superimposed on the functional design. If, however, the exigencies and limitations of production processes are kept in mind while the product is designed from a functional standpoint, the resulting design may logically be consistent with good manufacturing practice at no sacrifice of functional efficiency.

387. There are several **important phases** of production design that should receive careful consideration. The first of these is the possibility of **using standardized or stock parts,** and refers not only to commercial parts that may be purchased at a lower cost than the cost of manufacture in the parent organization (all factors considered), but also to such parts as are regularly manufactured and carried in stock in conjunction with the production and sale of other products. It is rarely difficult to adapt a design to standardized or stock parts at the inception of the problem, but it may require some sacrifice of functional efficiency and it always requires a great deal of work to substitute stock parts for parts of special design.

Chapter 2 describes some of the commercial products and sizes that may be utilized in design. In some instances it is possible to adapt a commercial article to a specialized application by one or more comparatively simple machining or manufacturing processes. In other cases manufacturers of such products can provide special parts at a slightly increased cost. Fig.

26-1 illustrates such an instance; oversize structural members can be readily obtained if the increase in size is made as indicated, and if the quantity required is sufficiently large. It should be emphasized, however, that instances rarely occur where a stock section, which is frequently rolled, cannot be as easily applied as a special shape.

388. The second important phase of production design should be **a consideration of the facilities** available for manufacture. It is evidently unwarranted, for example, to design for large-scale production a sleeve with an accurate square hole if no broaching equipment is available; it is equally futile to specify limits to .0001" on hardened steel parts if no precision grinding machinery or analogous equipment is at hand in the production division. The survey of available production facilities should not, in all instances, be limited to the resources of the parent organization; it should also be extended to include the possibility of sub-contract work by specialists who may be able to handle satisfactorily certain phases of manufacture.

Fig. 26-2 illustrates a rather interesting **design history**; as originally designed, the bracket shown at *A* was cut from a solid block of steel, which involved several difficult machining operations. In order to increase the rate of production and reduce the material and labor cost, the arc-welded design at *B* was substituted. This part was made of a piece of standard seamless tubing and two steel plates sawed to shape. An investigation of the functional design showed that the steel bracket could be replaced by one made of aluminum alloy, so the second design was in turn replaced by part *C* which was made from extruded bar stock supplied by a sub-contractor and machined as indicated. Further research on the functional design indicated that the two ends and the under side of the bracket base were the only plane surfaces that required finishing, and a malleable iron casting shown at *D* was found to be the most economical solution of the problem.

389. The third important phase of production design should be a consideration of the **possibilities and limitations of** the many and varied **production processes.** The respective fields of these processes have been described in previous chapters, but it should be emphasized that the production rate is a decidedly important factor in both the possibilities and the limitations of each process.

It is not possible, of course, in a text of this character, to do more than indicate in a general way the limitations of some of the more common manufacturing processes. The industrial perspective, however, changes so rapidly on account of the introduction of new methods and processes, that the engineer who is responsible for production design in any of its phases

should keep in touch with his field by frequent reference to the many excellent trade publications that are available.

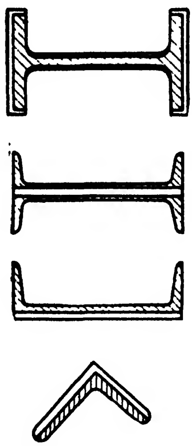


FIG. 26-1. Commercial Methods of Increasing Sectional Areas of Structural Steel Shapes.

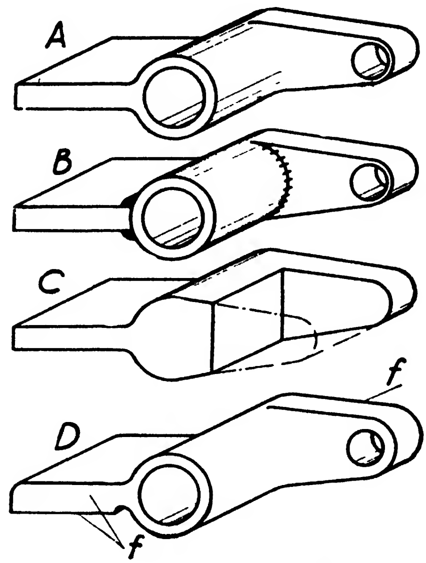


FIG. 26-2. Bracket Design.

390. Fig. 26-3 illustrates several important considerations in the **design** of **cast iron parts.** A sharp interior corner at the juncture of

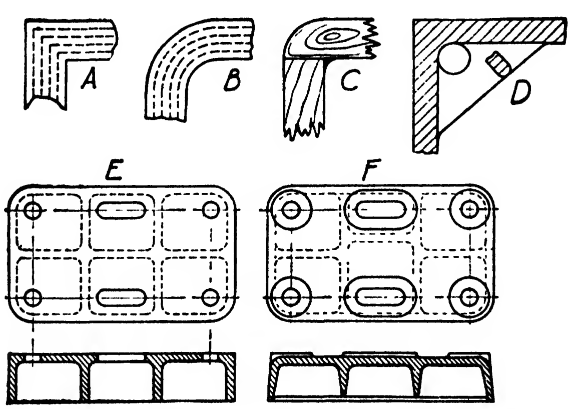


FIG. 26-3. Casting Design Principles.

two walls of a casting may cause a crystalline arrangement, as illustrated by the dotted lines at *A*, which tends to produce at this point a high stress

concentration which will increase the seriousness of the stress concentration already existing due to the form of the sharp interior corner. Neither sharp interior nor exterior corners can be realized in castings; metal does not fill an exterior corner perfectly and the flow of the molten metal tends to wash off the sharp edge of the mold for the interior corner. The sand that is washed off will probably reappear somewhere in the casting, which may result in a defective product. Concentric corner radii, as shown at *B*, will effect a good crystalline arrangement upon cooling. An exterior corner equal to the thickness of the casting wall, with a small wax or leather fillet in the interior corner as at *C*, offers the least expensive pattern construction because a separate corner section does not have to be made.

Fillets that are large in proportion to wall thickness may produce a large local accumulation of metal which may still be liquid when the outer walls have solidified. This condition may result in a porous interior or a blowhole. One solution for this problem is shown at *D*, where a large accumulation of metal was anticipated at the juncture of the two walls and the rib; the cored hole in the rib reduced the metal concentration and did not affect the functional design of the part.

Figures 26-3 *E* and *F* illustrate alternate designs for a machine base. The pattern for base *E* is less expensive than the one for *F*, and the part would probably be made in this manner if only a few castings were required. In base *F*, however, the walls and ribs are tapered so that the pattern draft is provided for without further consideration by the patternmaker, and the supporting ribs are offset to avoid metal accumulation. Base *F* has a series of bosses and pads on its upper surface and is finished only around the edge on its lower surface. This feature reduces the surface area to be finished, which is particularly important if the surfaces are to be finished by rough and finish grinding without preliminary machining, since the production rate in grinding operations is almost directly proportional to the extent of the area of the work.

Unless the slots and holes are very small, they should be cored, not only to facilitate subsequent machining processes, but also to permit the interior core to be supported while the part is cast. If no cored holes are provided, the core must be supported by chaplets.

Two designs of a machine bed are shown at *A* and *B*, Fig. 26-4. The bed at *A* has interior ledges or flanges which provide smooth lines and an excellent appearance. These flanges are difficult to cast, however, since either an interior core or a loose-piece pattern is required, and external flanges as at *B* are generally used. The attached bracket at *B* is superior to the integral part at *A*; the attached part requires more machining and is therefore more expensive, but the design at *A* is far more expensive to cast, and the entire part must be scrapped if the comparatively fragile

bracket is broken. The design at *B* also illustrates a feature which should be incorporated in the design of large beds and bases for machines: a recess to permit the insertion of a crow-bar for moving the machine during installation and erection. The application of this feature is shown in Fig. 25-11.

Two frame designs are shown in Fig. 26-4 at *C* and *D*. The symmetrical beads at *C* tend to lower the stress concentration in the casting, but the arrangement shown at *D* is easier to mold, particularly if an interior core is used. *E* and *F* illustrate alternate hub designs; the design at *F* requires a core but provides a sounder casting than the design of *E*.

G and *H* represent alternate designs of a rocker lever. The design at *H* is superior to that at *G*, not only because the lines are simpler and the pattern is less costly, but also because a plane parting line can be used in the process of molding.

In general, castings should be designed as simply as possible; walls should be of uniform or nearly-uniform thickness; machined surfaces should lie in the same planes if possible; and the use of constructions that involve difficult molding should be avoided. It is generally better to substitute two or more simple castings for one complex part.

391. There are several important details that must be carefully considered in **die casting design** in order to obtain the most satisfactory results at a minimum cost. In most cases inside sharp corners on die-castings should be avoided. Casting fractures start more readily in sharp than in rounded corners, and dies for sharp corners are generally more difficult to machine. If, as in Fig. 26-5, a part is to fit closely in an inside corner, a recessed corner is preferred.

Intricate recesses or *undercuts* should be avoided. The bearing end of the automobile window crank handle, Fig. 26-6, is an example of an undercut that is practically impossible to produce simply in a die. The bushing *A* of Fig. 26-7 offers no die-casting difficulties but that at *B*, with its undercut, closed-end oil groove, requires the use of an expensive collapsible core within the main core.

Intricate cores should be avoided. Unlike sand-castings in which the cores can be broken up for removal, die-castings must be designed to permit rapid withdrawal of the cores. The elbows of Figs. 26-8 *A* and *B* have cores that can be readily removed, as shown by the arrows, although the core of elbow *B* is expensive to make. The elbow at *C* has a core that requires considerable time to assemble and place in position.

Inserts may be used to save time in removing cores. Figure 26-9 *A* shows a die-casting with an internal die-cast threaded hole. An excessive amount of time is required to screw out the core from a fairly deep hole, and an insert shown at *C* may be preferred. The insert has a roughened or serrated outer surface to hold it firmly in the casting. The insert, if it be made of steel, will also give stronger threads than the die-cast ones. It

is sometimes found more economical to cast the hole without threads, as shown at *B*, and tap the threaded hole in a subsequent tapping operation.

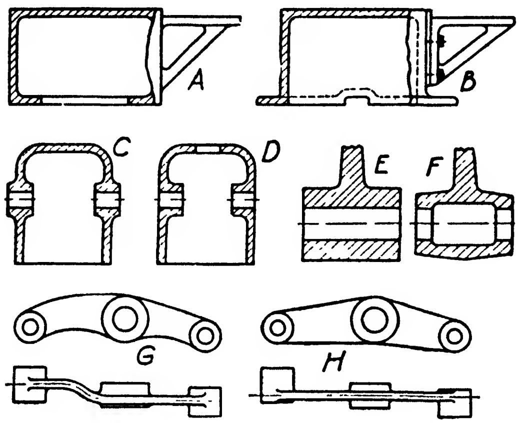


FIG. 26-4. Casting Design Principles.

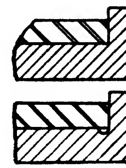


FIG. 26-5.

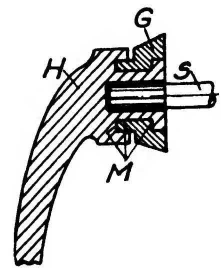


FIG. 26-6.

The difficulty of core removal is also illustrated in Fig. 26-7 *C*, where the helical oil groove in the bushing requires a combination of rotary and rectilinear motion for withdrawal.

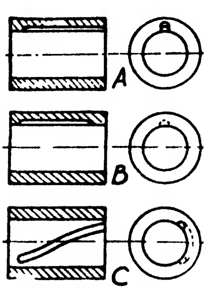


FIG. 26-7.

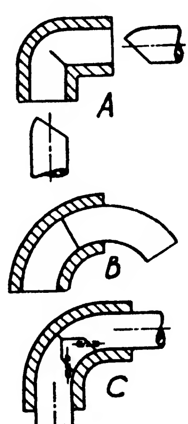


FIG. 26-8.

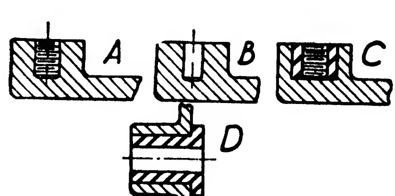


FIG. 26-9.

Inserts may be used to save assembly time. In many products, bronze or steel bearing sleeves are used since the die-casting material may not be satisfactory for this purpose. In Fig. 26-9 *D* the steel bearing sleeve is

cast in place instead of being pressed into position after the casting has been made. Its outer surface is serrated to hold it in place. Fig. 26-6 shows another die-cast assembly. Part G is die-cast in one die, removed from that die, and the bearing surfaces M are given a graphitic coating. The screw insert S and part G are then placed in a second die and the handle H

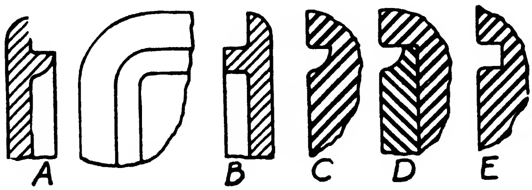


FIG. 26-10.

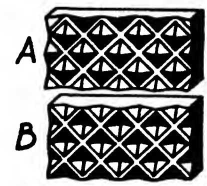


FIG. 26-11.

is cast in place. (Note that while it is practically impossible to die-cast H separately, it may readily be cast assembled.)

Complicated or expensive dies should be avoided. Figure 26-10 shows a die-cast cover plate of two alternative sections, A and B. It is very difficult to machine out of a solid block a die for section A like that shown at C. Therefore a two-piece die, D, is required. This die is more expensive than a one-piece die, and may cause trouble in casting production because

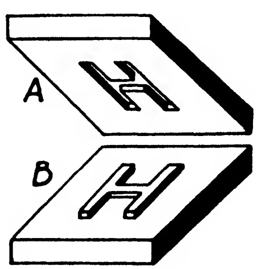


FIG. 26-12.

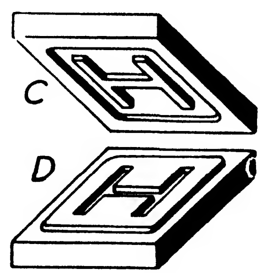


FIG. 26-13.

of uneven expansion of the parts. By using section B for the cover plate lip, the die can be made as at E, with a groove that can be readily cut by employing an end mill on a milling machine.

Depressed matting, Fig. 26-11 B should be used for decorated surfaces rather than raised matting, Fig. 26-11 A. The dies for the matting shown at A must be made by pressing or rolling, while those for the matting of B can be milled into the surface.

Raised letters should be used in preference to depressed letters. In Fig. 26-12, A is the die and B the resulting casting; the letter facsimile is

cut into the die. If B in Fig. 26-12 is the die and A the casting, all of the die surface around the letter must be cut away. If depressed letters must be used, the construction in Fig. 26-13 may be employed where C is the die and D the casting. The panel design reduces the amount of die material that must be cut away to provide a raised facsimile in the die for a depressed letter in the casting.

392. Dies for **plastic molded parts** are subjected to many of the limitations that control the design of die-cast parts. In using any specific material for plastic molding, it is advisable to consult the manufacturer of the material in order to take advantage of any particular features that it may possess, and to guard against any limitations that should be placed upon its use.

393. Forging design is somewhat analogous to both sand-casting and die-casting design. Forged parts should be as simple as possible with most of the material in the same plane. Undercut surfaces should be avoided; deep recesses are undesirable; and forgings should be designed, if possible, to permit plane parting surfaces in the dies. Forgings of complex shape with varying sections may require too many break-down operations for economical production. Drop forgings should be designed with at least 7° of draft since expensive trimming operations may otherwise be required. Drop forgings with deep holes are often made by punching the hole from both sides, as illustrated in Fig. 26-14, to leave a thin flash at the center which may be removed in a subsequent drilling operation. Hubs in drop forgings are often spotted to provide a starting point for a drill or to reduce the hub surface in sizing processes.

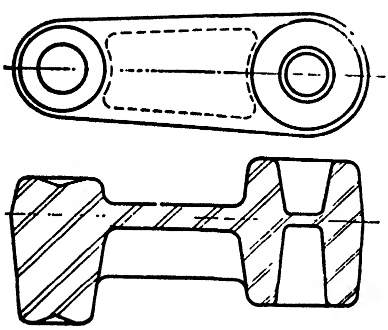


Fig. 26-14. Forging Design.

394. In many instances malleable iron castings can be substituted for forgings. **Malleable iron parts** may be designed with practically the same limitations that cast iron parts are subject to, but may often be subjected to bending or other fabrication processes after casting and cooling.

395. Fig. 26-15 illustrates several examples of correct and incorrect design in **pressed metal parts.** The drawing at A represents a small bracket which was blanked from sheet metal and bent to provide two ears for attachment to another part. The section of the development between the ears was so small that extensive die breakage was encountered. The redesign at B, in which the ears were placed on the outer edges, did not

affect the functional design of the part to any great extent and permitted a much more satisfactory die construction.

In designing a part which is to be bent after blanking, sufficient bending relief *X* should be incorporated in the design to avoid distortion of adjacent sections. In fitting one bent part in another, as at *C*, the inner bend radii of the two parts may be made alike if the parts are made of the same material and gage, but it is generally advisable to bend the inner member to a greater radius than the outer to eliminate any possibility of interference. Machined parts which fit into sheet metal angles should be chamfered as illustrated at *D*.

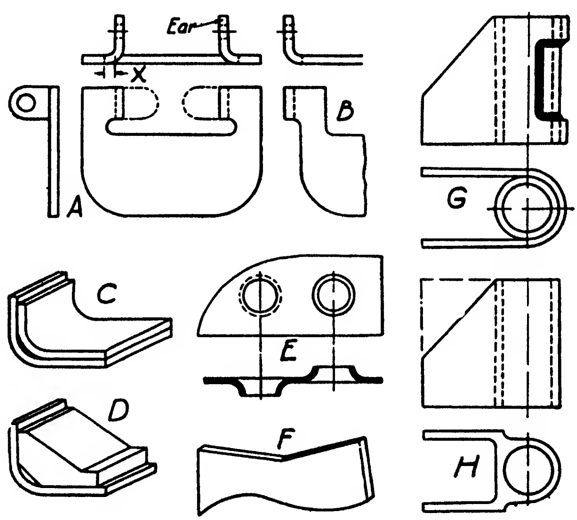


FIG. 26-15.

Flanged or burred edges of plates or holes should be flanged in one direction, if possible, and not from both sides as shown at *E*, since two-way flanging requires two operations in a die. The part at *F* shows two shapes, the curved lower profile and the straight-line re-entrant-angle profile, that are not particularly difficult to handle in blanking dies but are extremely difficult to cut satisfactorily on hand or power actuated shears. In cutting re-entrant angles it is practically impossible to control the shear blade so that the plate will not be slit; and irregular curves may be at best only approximated with a straight shear knife. For these reasons structural steel gusset plates are made with edges whose included angles are 180° or less. Large plates of curved outline should have a profile composed of circular arcs so that a power-actuated circle shear may be used in fabrication.

Pressed and blanked sheet metal parts should be made with rounded corners preferably of some standard size to facilitate die manufacture. Sharp corners in dies are often a source of trouble, since they may serve as a starting point for cracks which sometimes develop during heat treatment or in service. Too many large holes in a blanked part may require the part to be pierced after blanking in a progressive die, which takes more time than a single die and is not as accurate.

Designs that require special dies such as bulging or wiring dies should be avoided if possible, since the production rate on this type of die is lower on account of the handling that is required. In some instances die castings can be substituted for complex drawn work with excellent results.

G and *H*, Fig. 26-15, represent alternate designs for a bracket. The design at *G* was made from steel tubing and a folded sheet metal blank welded as indicated. The blank was punched as illustrated to provide adequate welding surfaces. The design at *H* represents an extruded replacement in which the hole was drilled and reamed after the stock for the part was cut from the extruded bar. The design at *H* is superior to that at *G* whenever the production rate warrants the initial expense involved in the use of the extrusion process.

396. Fig. 26-16 illustrates several examples of **redesign for arc-welding** to replace riveted joints in structural connections and castings in machine construction. The arc-welded column and beam connections may be used to replace a similar riveted connection in Fig. 2-8. The first alternate is similar in design to the riveted detail, and uses connection angles to join the *I*-beam and the *H*-column; the second alternate deviates from the conventional construction used in the riveting process but is less expensive to erect and weld than the first design. Three methods of welding roof truss joints are also illustrated and may be used to replace the riveted joint in the truss of Fig. 2-11. It should be noted that the gusset plates are eliminated and that several alternate forms of welding may be employed. Transverse or end welding is preferred to parallel or side welding, but the latter is often used on account of the limited joint lengths available. In some instances the upper chord angle is slotted so that a greater length of weld can be obtained.

Figure 26-16 shows the bracket or frame casting for the burring head of Fig. 3-2 and two alternate designs for arc-welded substitutes. The first alternate is practically an arc-welded steel replica of the bracket casting; the second alternate is designed to take advantage of the greater strength of the steel and results in much simpler construction. Either alternate is satisfactory from a functional standpoint but the second requires only a length of tubing and two plates, while the first requires a base plate, a

center rib, two specially-shaped end sections, a length of tubing and two washers. It should be noted that when iron castings are replaced by arc-welded steel parts, there is a justifiable tendency on the part of the designer to reduce the size and weight of the part in full proportion to the greater strength of the steel. This practice may, however, cause a loss in rigidity,

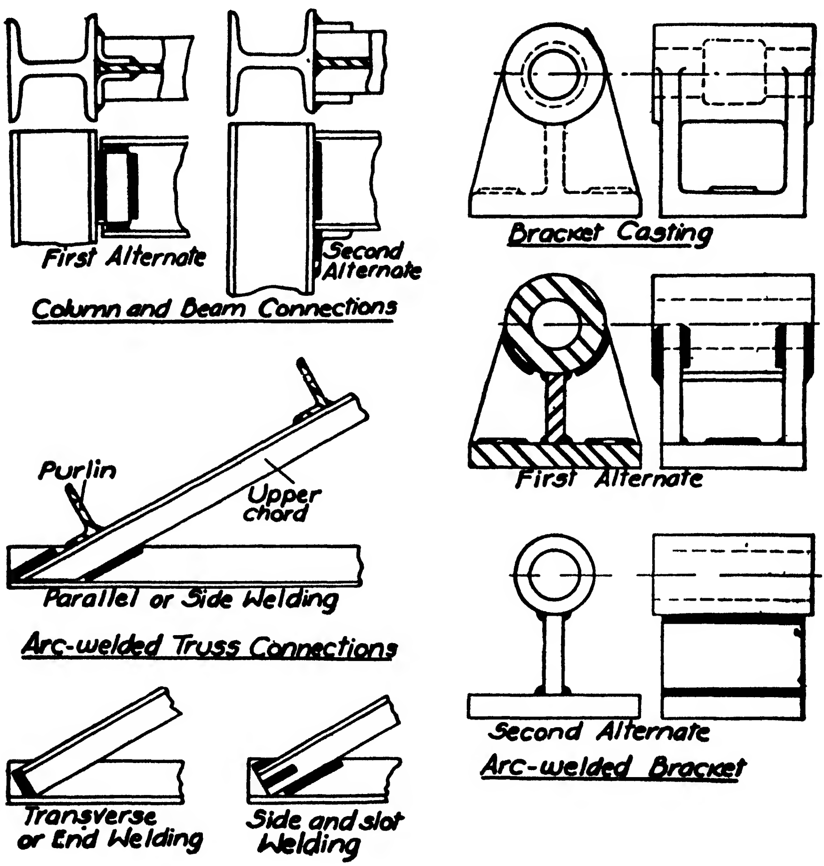


FIG. 26-16. Redesign for Arc Welding.

a factor which is sometimes overlooked in the design of arc-welded jigs and fixtures.

Other welded replacements are illustrated in Fig. 15-10 and 20-29. Figure 26-17, however, shows a design which was originally machined from solid bar stock, but was subsequently converted to a two-piece welded assembly in order to save machining costs and use a comparatively small

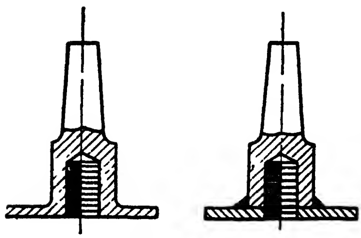


FIG. 26-17. Bar Stock and Welded Design.

bar for the shank of the piece. The two piece construction was abandoned after it was discovered that a drilling and tapping operation was required after welding. The part is at present machined from an upset forging.

397. Fig. 26-18 shows several examples of correct and incorrect design for **machining and surfacing processes.** The two-diameter hole at *A* may be cut with a multi-diameter or sub-land drill, but is more often drilled in two separate operations. In the latter case the larger hole should be drilled first as at *B,* since it is impossible to drill the large hole after the small hole has been drilled and maintain size or alignment accuracy. Even a four-lipped drill would be difficult to hold in alignment unless it is very carefully supported by drill jig bushings.

The figure at *E* shows the effect of drilling a hole which breaks into another hole, as at *D*. To maintain proper alignment, the small hole should be drilled first, then the large hole bored. If the small hole *must* be drilled after the large hole is finished, it is advisable to close the large hole temporarily with a plug made of the same material as the part. In drilling a hole whose axis lies on the surface of contact of two unlike materials, great care

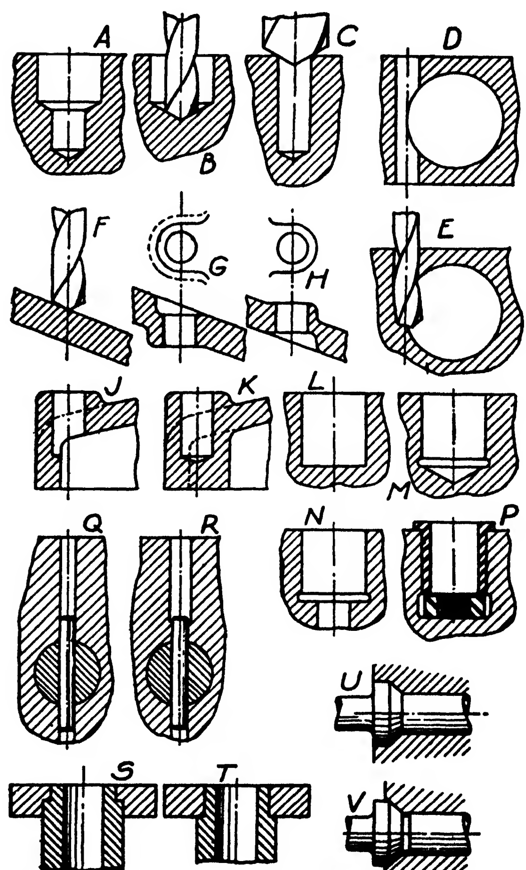


FIG. 26-18. Machining Principles.

must be exercised in order to prevent the drill from "working over" into the softer material.

It is very difficult to start a drill on an inclined surface, and provision for a surface perpendicular to the drill axis should be made in the design of the part as shown at *G* or at *H*. If a cast recess is impracticable, it may be possible to spot a surface with an end mill prior to drilling. The design at *J* is incorrect because the drill will tend to snag or catch after it ceases cutting on its full diameter; the construction at *K* is preferred, although it may result in some metal accumulation in casting. *Q* and *R* represent alternate designs for deep drilling; the design at *R* is preferred because it is easier to drill the small hole after the larger hole is in place, and because it is thereby unnecessary to drive the pin for a distance greater than its length.

Holes with precisely finished blind ends, as shown at *L*, are quite difficult to finish unless a recess as shown at *M* is employed to permit the boring tool to run out. A design which includes a small hole, as at *N*, is advantageous in that it reduces the area to be faced. If a bushing is inserted in a blind hole, it will be extremely difficult to remove unless some provision is made for this operation prior to forcing the bushing in place. The design at *P* shows a very simple method of accomplishing this purpose. Before the bushing is forced into place, a nut slightly smaller than the outer diameter of the bushing, but larger than the inner diameter, is placed in an enlarged recess in the hole so that the bushing can be *pulled* by screwing a bolt into the nut. In the design shown at *P*, the bushing head is seated against the outer surface of the frame and the bottom of the hole need not be accurately faced. A similar design is shown at *M*, in which the conical surface left by the end of the drill need not be faced perpendicular to the axis of the hole. The total machining time for the hole shown at *M* is about one-half that required for the hole at *L*. The possibility of substituting spot facing for bosses should be kept in mind to reduce molding costs.

S and *T* illustrate two methods of seating flanges on cylinders; the design at *S* is more costly, and not particularly better, than the design at *T*. *U* and *V* illustrate two methods of designing conical thrust collar bearings. The design at *U* requires either several operations to machine the countersunk-counterbored end of the hole, or a special combination tool; the countersunk end at *V* can be produced in one comparatively simple chamfering operation. The shaft design at *V* is better than at *U* because the groove at the juncture of the straight and conical portions of the shaft will permit sufficient clearance for grinding both these surfaces.

Figs. 26-19 *A*, *B*, and *C* illustrate several methods of finishing shaft, pin, and bolt ends. If at all possible, it should be permissible for the production division to leave the center holes shown at *A* in the work. The func-

tional efficiency of a part is rarely if ever affected by the presence of center holes, and it is comparatively expensive and generally requires two additional operations to cut off the ends of the part to effect the removal of the center holes.

Parts turned in a lathe should have rounded corners as shown at *B*, instead of the chamfer shown at *A*. The shaft end shown at *C* is comparatively expensive as an engine lathe operation but is extensively used for turret lathe and screw machine parts, since the curved profile permits a stronger cut-off tool shape than the other two designs. As described in

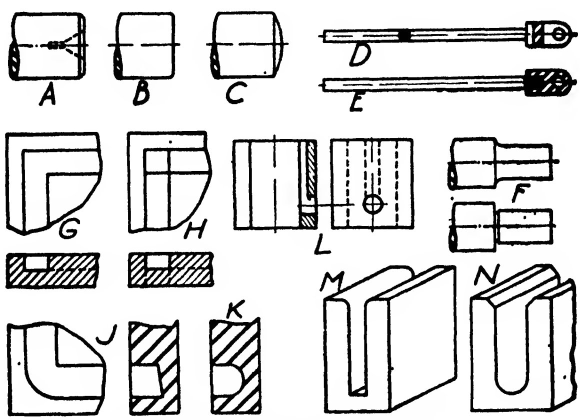


FIG. 26-19. Machining Principles.

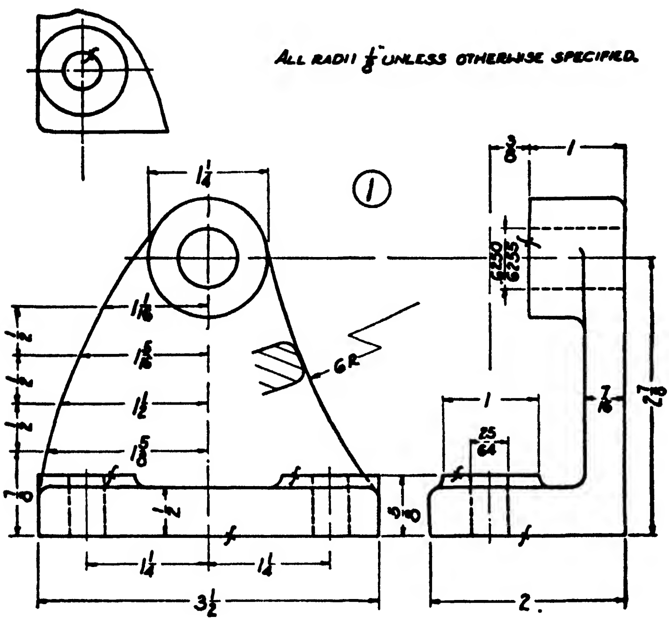
Chapter 11, shafts with a center hole in one end and a cylindrical or conical hole in the other are generally expensive to turn. Shaft diameters are often varied to facilitate assembly, but should be as nearly alike as possible to avoid excessive turning.

The design at *D* shows a small rod which was expensive to make, since it required a series of turning operations at low rates of feed with shallow depths of cut to eliminate spring. The redesign at *E* permitted the rod end to be made of bar stock with a decided increase in the production rate, and was just as satisfactory from a functional point of view.

The detail at *F* shows two designs of shaft necks; the filleted corner is definitely superior if the shaft is subjected to high stresses, since there is very little stress concentration at a smooth, large-filleted corner. The design with the grinding neck, however, permits grinding both the diameter and the face of the shoulder without difficulty and should be introduced whenever possible.

Interior keyways should extend entirely through the part since they can then be broached if desired. Blind keyways, as at *L*, require a drilled

hole to permit the slotting tool to run out. This drilled hole should be at least $\frac{1}{16}''$ larger than the width of the finished keyway. Square and splined fiting design should adhere rigidly to the S.A.E. standards for such details so that standard broaches, which are usually easier to obtain quickly, may be employed. Blind square and hexagonal holes should be avoided if



BILL OF MATERIAL			IDLER PULLEY ASSEMBLY		
DWG.	PART No.	PART NAME	No REQ.	MAT'L	DATA
66	1	BRACKET	1	C.I.	
68	2	PULLEY	1	C.I.	
68	3	STUD	1	M.S.	CASEHARDEN
	4	OIL-HOLE SCREW	1	M.S.	3/8-16-USS-HOLLESS SET SCREW
					1/2 LONG—FLAT POINT

FIG. 26-20. Idler Pulley Assembly Details.

possible, since the only effective method of finishing such holes is by punch-broaching. Forged and cast square and hexagonal blind holes offer no major production difficulties.

The detail at *G* illustrates a square-edged groove which is practically impossible to machine. The only method of machining is shown at *H* in which a circular hole is drilled in the corner and is slotted out to form a square. The grooves leading to the hole can then be milled. The exterior

corner of a groove should always be circular with a radius preferably not less than one-half the width of the groove. Inclined groove bottoms should be avoided. Two end milling operations are required to mill the obtuse angle of the groove at *J*, and at least two milling operations and a hand filing operation are required for the acute angle. The groove at *K* is not

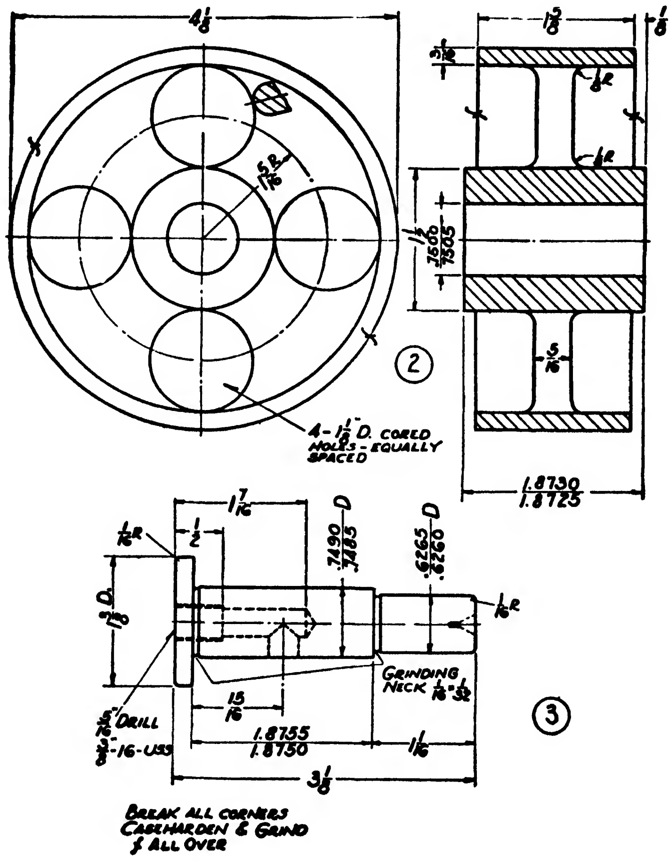


FIG. 26-21. Idler Pulley Assembly Details.

particularly difficult to produce if a peripheral cutter such as a convex form cutter can be used, but it is difficult to cut with an end mill. Corner radii in the profile of slots and grooves should not exceed one-fourth the groove width.

Deep slots like those shown at *M* should be avoided unless the slot is made wide enough to mill with an arbor-type helical mill. In that case, the bottom of the slot should preferably be semi-circular so that a subsequent

slotting or broaching operation is eliminated. Chamfered corners as at N are preferred to rounded corners, since it is generally easier to mill plane surfaces than those which have curved profiles.

398. Figs. 26-20 and 26-21 represent a complete set of detail drawings and a bill of material for an idler pulley assembly. This device is employed to increase the arc of contact of a belt drive and regulate the tension in the belt. It consists of a loose pulley which is free to rotate on a stud forced into a hole in the bracket. The pulley is lubricated from the central oil hole in the stud; the set screw prevents the oil from running out. The stud is assembled so that the cross oil hole is in a horizontal position in use to prevent an excessive flow of the lubricant. These details represent **current practice in specification,** and are introduced to show the application of some of the manufacturing limitations described in this chapter.

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Colvin, F. H., and Stanley, F. A.—Turning and Boring Practice, 1st ed., 1936, McGraw-Hill. Chaps. 7 to 18, incl.

Periodicals

Burlingame, L. D.—High-speed Cutting of Brass in Standard Machine Tools ME-1925-47-9-705
Machining operations on milling machines and automatic screw machines on brass and other soft metals; examples of processed parts.
Burlingame, L. D.—Screw Machine Products Made in Less Than Three Seconds M-1923-29-7-507
Manufacture of small parts on B. & S. automatics.
Herb, C. O.—Modern Automatics M-1937-43-12-765
Application of automatic screw machines to bar stock, forged and cast parts.
Machining Stainless Steels on Automatic Screw Machines AM-1939-84-7-195
Miller, R. E.—High-production Machines for Short-run Work IA-1938-142-14-26
Application of Bullard Mult-au-matics to small-lot production.
Obtaining Production on the Vertical Turret Lathe M-1921-27-6-535
Typical examples of production and tooling.

Chapter 23—Production Milling and Allied Operations

Books

Boston, O. W.—Engineering Shop Practice, Vol. I and II, 1st ed., 1933, Wiley. Chap. 6, Vol. I; Chaps. 3 and 4, Vol. II.
Colvin, F. H., and Stanley, F. A.—Drilling and Surfacing Practice, 1st ed., 1936, McGraw-Hill. Chaps. 18-31.
Gear Cutting Practice, 1st ed., 1937, McGraw-Hill.

Jones, F. D.—Machine Shop Training Course, Vol. II, 1st ed., 1940, Industrial Press.

Kent, R. T.—Mechanical Engineers' Handbook, Vol. III, 11th ed., 1938, Wiley. pp. 21-33, 21-46.

Periodicals

Broached Rifle Parts AM-1938-83-22-902
Analysis of operations; proper application of locating points; machines and broaches used. AM-1938-83-24-994 AM-1938-83-25-1032

Cam Cutting on a Gear Shaper M-1938-45-1-12

Climb and Conventional Milling Advantageously Combined M-1937-43-10-668

Gear Manufacture in a Machine Tool Plant ... AM-1939-84-5-121

Herb, C. O.—Machining Operations on the McDonald Observatory Telescope M-1935-42-4-233

Herb, C. O.—Making Gears for Transmitting Eight Thousand Horsepower M-1938-44-9-583

Herb, C. O.—Unusual Jobs on Keller Machines M-1935-41-12-713
Tool-room and production operations performed on contour milling machines.

Herb, C. O.—Packard Practice in Cutting Hypoid Gears M-1937-43-8-520

Machining Navy Turbine Blades AM-1939-84-25-1016
Using standard milling machines with special fixtures.

Marthens, R. S.—Control in Gear Manufacture IA-1939-144-25-33
Controlling finished dimensions, quality, and heat-treatment.

McFarland, E.—Manufacture of the Bolt of the Springfield Army Rifle ME-1924-46-8-463
Operations; methods; special tools and fixtures; gaging.

Romaine, M.—Broaching Cylinder Blocks and Heads M-1938-44-8-516
Application of surface broaching to automotive parts.

RotoMill, The IA-1938-142-6-39
A machine for finishing surfaces of revolution by milling.

Smear, H. W.—Cutting High-speed Reduction Gears IA-1938-141-20-24

Wiese, R. R.—Gear Manufacture in a Tractor Plant AM-1938-83-26-1071

Young, G.—Modern Methods in Gear Manufacture M-1940-47-2-107

(*See also* Chap. 21.)

Chapter 24—Production Surface-finishing Processes

Books

Boston, O. W.—Engineering Shop Practice, Vol. II, 1st ed., Wiley.
Chaps. on grinding, polishing, buffing, honing and lapping.
Colvin, F. H., and Stanley, F. A.—Grinding Practice, McGraw-Hill.
Heywood, J.—Grinding Wheels and Their Uses, 1st ed., 1938, Penton Publ. Co.
Swigert, A. M., Jr.—The Story of Superfinish, 1st ed., 1940, Lynn Publ. Co.

Periodicals

Bowman, F. D.—Modern Abrasives Celebrate Their Fiftieth Anniversary M-1941-47-7-128
A brief history of the discovery and development of modern abrasives.
Andrews, J. E.—Honing Engine Cylinders ... M-1937-43-8-526
Appleton, C. T.—Commercial Cylindrical Lapping ME-1925-47-12-1106
Operation of production lapping machines; tolerances; methods of lapping piston pins.
Blood, H. L.—Automatic Internal Grinder ... ASME-1932-MSP-54-1
Development and application of grinder with automatic sizing device.
Connor, K. W.—Finish Processing of Ordnance and Tubing Bores IA-1939-143-2-17
Applications of production honing. IA-1939-143-8-26
Honing in the Aircraft Industry M-1939-45-11-776
M-1939-45-12-874
The Hone's Zone AM-1938-83-5-135
Divine, B. H.—Prerequisites of Successful Polishing ASME-1928-MSP-50-6
Design of parts to facilitate polishing; abrasives and adhesives used; types of wheels.
European Thread Grinding Practice M-1939-46-4-255
Flanders, R. E.—American Thread Grinding Practice M-1939-46-1-1
Gaertner, W.—Cutting a Lead Screw of Unusual Accuracy M-1925-31-10-
Harris, D. H.—The Gillette Abrasive Stone Comparator IA-1940-146-8-32
Description of a machine for testing abrasive stone hardness with a rotating diamond-pointed drill.
Hoke, W. E.—Precision Lapping M-1925-31-8-593
Kent, R. T.—Fundamentals of Machine Polishing ASME-1931-MSP-53-9
Work and machine variables; typical operations; economics.

Mehlhope, L. E.—Finishing Shells by Centerless Grinding M-1941-47-7-145
Mueller, P. M.—Precise Cylindrical Lapping.. ME-1925-47-9-701
Work preparation; methods of production lapping; measurement.
Page, D. C.—Internal Centerless Grinding ... M-1936-43-4-233
Peaslee, R. W.—Centerless Grinding in Small-lot Production AM-1939-84-24-960
Peets, W. J.—Theory and Practice of Centerless Grinding ME-1925-47-9-695
ME-1925-47-11-943
Precision Surface Grinding M-1936-43-2-97
Rose, J. B.—Machining and Lapping Very Deep Holes ME-1922-44-12-807
Drilling, reaming and lapping very long holes in gun-recoil mechanisms; (see also AM-1923-52-pp. 595, 937, 1049, 1094).
Player, S.—Mechanical Lapping ASME-1930-MSP-52-14
Wiese, R. R.—Cutting with Abrasives AM-1939-85-4-101
Using abrasive wheels for cutting off stock.
Wills, H. J.—Lapping for Final Finish AM-1938-83-24-985
Description of process; abrasives used; machine lapping. AM-1938-83-25-1037
AM-1938-83-26-1080
AM-1939-84-1-5

Chapter 26—Production Design Considerations

Books

Olsen, J. K.—Production Design, 1st ed., 1928, McGraw-Hill.
Design and specification affecting quantity production of metal products.
Principles of Interchangeable Manufacturing—Industrial Press.

Periodicals

Charlton, E. J.—Shall It Be Welded? PE-1937-8-7-258
Design details for welded frames and baseplates; flame-cutting; limitations of process. PE-1937-8-8-310
Chase, H.—Die Cast or Stamped PE-1938-9-8-282
PE-1938-9-10-398
Die Castings or Plastics PE-1939-10-8-320
Die Cast or Sand Cast PE-1940-11-2-53
PE-1940-11-4-165
An excellent series of articles on relative costs, possible applications, and design advantages of various manufacturing processes. Design histories of numerous parts are included.

Correct Casting Design PE-1941-12-3-135
Design details that facilitate sand-casting production and improve sand-casting quality.

Designs for Speedier Production PE-1941-12-4-153
Design details to facilitate production, save machining time, and shorten assembly time. Examples of alternate designs to facilitate production are included. Design histories of numerous parts are also shown.

Dumaine, P., and Cederholm, E. E.—Precision Parts PE-1940-11-6-260
Design details that facilitate machining problems on small pivots, screws, and wheels for watches, timers and instruments.

Fagan, J. C.—Steps in a Modern Design PE-1940-11-9-404
Design history of a thermostatically-controlled electric iron.

Fisher, O. W.—Welded Constructions PE-1938-9-8-296
PE-1939-10-4-146
Details of welded assemblies for sanitary and chemical-processing equipment; various types of joints, supports, and outlets.

Nenninger, L. F., and Maddox, W. A.—Precision Machine Tools Built by Welding...IA-1938-142-23-26

Schneider, P. F.—Redesigning Die Castings...PE-1940-11-12-570
Design histories of parts in which die casting economies were effected by changes in construction.

Welding Symposium ....ASME-1936-MSP-58-1 to MSP-58-9, incl.
A series of papers on welding design and its application to ferrous and non-ferrous metals.

Webber, H. M., and Swansen, T. L.—Redesigning for Furnace Brazing PE-1940-11-10-448
PE-1940-11-11-518
Design histories of parts in which castings or forgings were replaced by stamped parts which were brazed after assembly.

Hydraulically-actuated Machinery

Hydro-electric controls for clamping and feeding in multiple-spindle automatic screw machines PE-1937-8-7-247

Hydraulic Circuits—Theory and Principles—A. H. Dall PE-1939-10-8-336

Hydraulic Feeds for Machine Tools PE-1939-10-10-414
Details of mechanisms for milling, grinding and broaching machinery.

Hydraulic Circuits—for various types of production machinery—J. C. Cotner PE-1940-11-5-228
PE-1940-11-6-274
PE-1940-11-9-412
Pneumatic Circuits—for controlling and operating machine cycles—L. A. Ward PE-1940-11-6-255
PE-1940-11-7-318
Symposium on Hydraulic Feeds for Machine Tools ASME-1928-MSP-50-4
Hydraulic System for a Small Grinder—Price, R. E., and Firnhaber, F. A. M-1939-46-3-183
Principles of Hydraulic Systems Applied to Machine Design—C. Morey M-1932-38-8-584
M-1932-38-9-673
The Hydraulic Operation of Machine Tools .. M-1937-43-9-576
10-648
12-777
M-1937-44-1-9
3-186
4-235
M-1938-45-1-29

Ingenious Mechanisms for Designers and Inventors, 1st ed., F. D. Jones, Industrial Press. Chap. 15—Hydraulic Transmissions for Machine Tools.

QUESTIONS AND PROBLEMS

The question and problem material in this book is grouped under three classifications: A—questions which may be answered without the use of the text as reference; B—questions and problems which require the use of the text as a reference; C—questions and problems which for their solution may require the use of reference material from the bibliography as well as the text. In the first two classifications, the "odd-numbered" and the "even-numbered" questions are arranged in parallel, and cover essentially the same text material, to enable the instructor to use different sets of questions for concurrent or consecutive student groups. Questions in any of the three classifications may be assigned for outside study; it is suggested, however, that a selection from the questions in classification A be employed for brief examinations at the beginning or end of the lecture period. Written reports may be based upon many of the questions in classifications B and C. The material in the bibliography, particularly that listed under Chapter 26, may also be used for this purpose.

CHAPTER 1

Classification A

1. What is meant by the term "characteristic of a material"?
2. What is the essential difference between material characteristics and material properties?
3. What is the difference between a force and a stress?
4. What is meant by the term "factor of safety"?
5. A bar 2 inches in diameter is subjected to a pull of 10 tons at each end. What is the magnitude and type of unit stress?
6. A bar is made of a material that weighs 0.26 pounds per cubic inch. The material will rupture at a unit stress of 55,000 psi. If the bar is held at its upper end and hangs freely, how long may the bar be before it breaks of its own weight?
7. What is the difference between the proportional limit and the yield point of a material?
8. What is meant by the term "modulus of elasticity"?
9. If a wire rope has a breaking strength of 10 tons, and is used for a 4,000 pound hoist, can you definitely determine the factor of safety? Explain.
10. Sketch a stress-strain diagram for a mild steel specimen, and indicate the important data, such as proportional limit, yield point, etc.
11. Describe the SAE system of steel classification.
12. What is the essential difference, as far as carbon content is concerned, between cast iron, wrought iron and steel?
13. What is the principal element that gives wrought iron its corrosion-resistant qualities?
14. What is meant by 18-4-1 and 18-4-2 steels, and where are they used?
15. In general, how does the strength of a steel vary with its carbon content and hardness?
16. What are the general effects of various alloys on steel strengths?
17. What is the essential difference between brass and bronze?
18. What is the essential difference between Monel metal and other alloys?
19. Describe the principle of operation of the Shore Scleroscope.
20. Describe the principle of operation of the Brinell Tester.

Define or explain the following terms:

21. Quenching. 22. Carburizing. 23. Nitriding. 24. Drawing. 25. High-speed steel. 26. Cementation. 27. Rockwell number. 28. Case-hardening. 29. Cyaniding. 30. Stainless steel. 31. Ni-resist. 32. Everdur. 33. White metal. 34. Babbitt. 35. Alclad. 36. Duralumin. 37. Parkerizing. 38. Sherardizing. 39. Carboloy. 40. Thiokol. 41. Buna. 42. Bonderizing 43. Aluminum bronze. 44. Dowmetal.
45. Why are lubricants employed in engineering practice?
46. What considerations are important in the choice of a suitable lubricant?
47. How is oil viscosity determined?

48. What is meant by a viscosity number?
49. What is the difference between an oil and a grease?
50. Explain the construction and application of oilless bearings.
51. What is a cutting emulsion?
52. Why are lubricants employed for metal-cutting processes?
53. What factors should be considered in the selection of a lubricant for metal-cutting?
54. What mechanical means are used for applying cutting lubricants?
55. Differentiate between paint, enamel and lacquer.
56. Differentiate between varnish and shellac.
57. Define and differentiate between pigment, vehicle and thinner.
58. Differentiate between natural and synthetic plastics, and name three important natural plastics.
59. Differentiate between thermo-setting and thermo-plastic compounds.
60. What is the principal field of application of hard rubber?

Describe the following plastics, and give one important application of each.

61. Tenite. 62. Bakelite. 63. Celluloid. 64. Beetle.
65. Define Portland cement.
66. What is the essential difference between cement, concrete and mortar?

Classification B

In the following SAE steel classifications. name the principal alloy and its approximate percentage, and give the approximate carbon content:

67. SAE 1035. 68. SAE 4135. 69. SAE 3250. 70. SAE 2330. 71. SAE 7260. 72. SAE 9250. 73. SAE 6140. 74. SAE 5130.
75. A concrete floor has a surface area of 400 square feet and is 6 inches thick. How many cubic yards of stone will be required if a 1-3-5 mixture is used?
76. A machine base is 10 feet long, 6 feet wide, and 30 inches high. How many barrels of cement will be required if a 1-2-4 concrete mixture is used?

Explain why the following engineering devices or elements are made of the indicated materials—why the material is employed for that specific purpose, what important physical characteristic is exemplified in its selection, and why the particular material is preferred to some other material:

77. Aluminum pistons for automobiles.
78. Hardened steel ball bearings.
79. Monel metal food-handling machinery.
80. Hard-rubber lined tanks for acid storage.
81. Small brass machine screws.
82. Lead pipe.
83. Asbestos brake linings.
84. Zinc die castings.
85. Stellite tool bit for metal cutting.
86. Alloy-steel automobile rear axle.

87. SAE 9250 steel valve springs.
88. Structural steel roof truss member.
89. Pressed steel automobile fender.
90. Leather belt for machine tool power transmission.
91. Forged steel tool holder for Stellite tool bit.
92. Babbitted bearing.
93. Duralumin airplane strut.
94. Tenite automobile steering wheel.
95. Zinc die-cast radiator ornament.
96. Brass water pipe.
97. Wrought iron water pipe.
98. Magnesium fittings for airplane parts.
99. Pressed steel for transmission pulleys.
100. Rubber belt for driving water pump.
101. Copper wire for electrical circuits.
102. Bakelite floor plugs for electrical fittings.
103. Carboloy tool bit for metal cutting.
104. Cast iron for air-compressor bases.

CHAPTER 2

Classification A

1. How many board feet are contained in a 2″ x 8″ joist 15 feet long?
2. How many board feet are contained in surfaced studding 1⅝″ x 3⅝″, 12 feet long?
3. What is the difference between plough and dado cuts?
4. What is the advantage and disadvantage of pin tenons?
5. What is meant by a 20″-100# I beam?
6. What is meant by a 3″ x 2½″ x ¼″ angle?
7. Why are plate girders and built-up columns employed in preference to solid sections?
8. Sketch a cold-formed high-strength steel replacement for a plate and channel column.
9. What is the essential difference between permanent and removable fastenings?
10. What media are used for permanent and for removable fastenings?

Sketch the following screw thread profiles; give the included angle of the thread; and indicate the principal application (power transmission, fastening, etc.):

11. Whitworth. 12. American Standard. 13. Square. 14. Acme. 15. British Ass'n Std. 16. Harvey Grip. 17. Aero. 18. Knuckle. 19. Dardelet. 20. Buttress.
21. Differentiate between the several types of American Standard thread series.
22. Differentiate between metal screw, wood screw, and pipe threads.
23. What is meant by the term "six penny" nail?

24. What advantages have self-tapping screws over the usual form of screw thread?

Sketch the following fastening elements:

25. Stove bolt. 26. Expansion bolt. 27. Turnbuckle. 28. Stud. 29. Fillister head cap screw. 30. Allen set screw. 31. Collar screw. 32. Castellated nut. 33. Wing nut. 34. Woodruff key. 35. Pratt & Whitney key. 36. Taper dowel.
37. Differentiate between flanged and screwed pipe joints.
38. What are the respective fields of globe and gate valves?
39. What is meant by a 3″ x 3″ x 2″ tee?
40. What is meant by O.D. pipe?
41. For what purposes are springs used?
42. Show by a sketch how a compression spring can be used for a tensile load.
43. What is meant by a circular mil?

Sketch the following:

44. Reducing tee. 45. Torsion spring. 46. 90° pipe elbow. 47. Check valve. 48. Hard-rubber lined pipe. 49. Disc spring. 50. Screwed union.

Classification B

51. What is the actual outer diameter of 1¼″ standard steel pipe?
52. What is the actual inside diameter of 2″ double-extra heavy steel pipe?
53. What is the inside diameter of ½″, No. 10 gage brass pipe?
54. What is the diameter of a 500,000 circular mil wire?
55. What is the major diameter of a No. 8-36 screw?
56. What is the thickness of a No. 4 steel plate?
57. Explain the function of the dowels *J* in Fig. 21-2.
58. Explain the function of the taper pin, Fig. 3-2.
59. Name and describe the function of the screws shown in Bar No. 4, Fig 10-44.
60. Name and describe the function of the screws shown in Fig. 3-8.

CHAPTER 3

Classification A

1. Differentiate between constant, varying, and adjustable speed motors.
2. Sketch and name the essential elements of a d.c. motor.
3. What advantages have squirrel-cage motors over other types?
4. Why are single-phase motors employed when possible?
5. What is a synchronous motor?
6. What are the relative advantages of split-phase and capacitator motors?
7. What is a shaft?
8. Differentiate between shafts, spindles and axles.

9. Why is transmission shafting made in such sizes as 15/16", 2 7/16", etc.
10. How may bearings be classified?
11. What is meant by "fluid-film" lubrication?
12. Name and describe four methods of lubricating bearings.
13. Sketch and describe three types of bearings for reciprocating slides.
14. What advantages have rolling over sliding bearings?
15. Describe the three series of radial ball bearings.
16. Differentiate between cylindrical and needle roller bearings.
17. Differentiate between Timken and Hyatt roller bearings.
18. Differentiate between couplings and clutches.
19. Differentiate between rigid and flexible couplings.
20. Describe the four sub-classifications for effecting power transmission between non-coincident shafts.
21. Why should the driven wheel be made of the harder material in friction wheel drives?
22. What rule should be followed for satisfactory quarter-turn belt operation?
23. Describe two methods of preventing belts from leaving pulleys in parallel-shaft drives.
24. Describe the operation of a "tight-and-loose pulley" countershaft.
25. Describe the operation of a reversing-drive countershaft.
26. What are the respective merits of group and individual drives?
27. What is the field of application of vee and round belting?
28. What is meant by the term "—a 2"—8 x 37 wire rope?
29. Describe three types of hoisting chain.
30. What are the respective fields of chain and gear drives?
31. What are the respective fields of detachable link, pintle, and silent link chains?

Sketch the following:

32. Ring-oiled bearing. 33. Helical gearing. 34. Jaw clutch. 35. Hypoid gearing. 36. Cylindrical worm gearing. 37. Rack. 38. Herringbone gearing. 39. Silent chain. 40. Block chain. 41. Globoidal worm gearing. 42. Spiral bevel gearing. 43. Drum cam. 44. Radial cam. 45. Roller chain. 46. Coil chain. 47. Spiral gearing. 48. Adapter-type ball bearing. 49. Friction clutch. 50. Dovetail slide. 51. Taper roller bearing.
52. What is meant by harmonic motion?
53. Why are linkages preferred to cams?
54. Why are eccentric-and-block drives preferred to constant-diameter cams?

Classification B

55. Explain fully what is meant by the specification "a 312 radial ball bearing."
56. In the countershaft of Fig. 3-19, if the diameters of the steps of cone *C* are 8", 10" and 12", and the diameters of the steps of the cone pulley on the machine are 10", 8", and 6", find the three possible speeds of the machine spindle if the countershaft *S* rotates at 300 r.p.m.
57. In the cam development shown in Fig. 3-39, how many seconds of feed time will result if the cam drum rotates once every four minutes?

58. In Fig. 11-28, if the gear teeth are 6-pitch, how far will the ram move when the pinion is rotated one-fourth of a turn?
59. A worm gear set has a triple-threaded worm and a 51-tooth gear. What is the speed ratio?
60. A pair of spur gears have 6 pitch teeth, and have 20 and 40 teeth. What is the center distance?
61. A helical gear has a normal pitch of 6 and a 30° helix angle. What is its pitch diameter if it has 45 teeth?
62. A worm gear has 30 teeth, 1″ pitch. The center distance between the worm and gear is 6″. What is the pitch diameter of the worm?
63. A spur gear has 15 teeth, 1½″ pitch. What is its pitch diameter?
64. A pair of bevel gears have 20 and 40 teeth, 5-pitch. What is the pitch cone angle of the pinion if the gears operate on a 90° shaft angle?
65. A silent chain drive has a sprocket with 19 teeth 1″ pitch and rotates at 1400 r.p.m. What is the chain speed? Do you think it is excessive? Explain.
66. Explain the application and function of the eccentric bearing shown in Fig. 25-13.
67. Describe the construction of a precision grinding machine head.
68. Sketch and describe a plain bearing and its ball bearing redesign.

CHAPTER 4

Classification A

1. What is meant by the term "unit-production system"?
2. What does measurement involve?
3. What are, and what is meant by, the two kinds of accuracy?
4. What is the fundamental standard of length?
5. In what fundamental regard does angular measurement differ from linear measurement?
6. What is the definition of a straight-edge?
7. In what way does the definition of a straight-edge depend upon the process of origination?
8. How may an internal square be originated?
9. Differentiate between allowance, clearance, and interference.
10. What simple ratio between the inch and the meter is used in industrial practice in the United States?

Sketch and describe the following:

11. Combination square. 12. Scribing caliper. 13. Spring calipers. 14. Screw thread micrometer. 15. Telescoping gage. 16. C-clamp. 17. Dial test indicator. 18. Surface gage. 19. Combination set. 20. Box parallels. 21. Vernier height gage. 22. Center gage. 23. Center head. 24. Fillet and radius gage.
25. Describe the construction and operation of a micrometer caliper.
26. Describe the method of reading a ten-thousandths micrometer.

27. Describe the application of an inside micrometer.
28. How may a telescoping gage and an outside micrometer be used as a substitute for an inside micrometer?
29. How may an outside caliper and an inside micrometer be used as a substitute for an outside micrometer?
30. Can a screw thread micrometer be used for measuring cylinders? Explain.
31. What are precision gage blocks?
32. What causes precision gage blocks to adhere?
33. Describe the essential features of a toolmaker's microscope.
34. Explain how the toolmaker's microscope may be used to find the center distance between two accurately bored holes in a rectangular steel block.

Classification B

35. How may an external square be originated?
36. Describe classes 1, 3, 5 and 7 of the ASA standard fits.
37. Describe classes 2, 4, 6 and 8 of the ASA standard fits.
38. Give the vernier and micrometer readings of Fig. 4-44.
39. Give the vernier and micrometer readings of Fig. 4-45.
40. Explain the shaft alignment operation shown in Fig. 4-38.

Describe and explain the measuring operations and procedures shown in the following illustrations:

41. Fig. 4-36. 42. Fig. 4-39. 43. Fig. 4-10. 44. Fig. 4-26.
45. In Fig. 4-42, if $A=40°$, $B=1''$, $D=1\frac{1}{2}''$, $E=3''$, and $C=4''$, what must the necessary height of a gage block stack be in order to measure the distance from the center of D to the base?
46. In Fig. 4-37, if angle A is 60° and distance B is 4″, what will distance C measure if rods with a diameter D of $\frac{3}{4}''$ are used for measuring purposes?
47. In Fig. 4-41, $C=6''$, $D=3''$, and $B=2''$. What is the angle A, and what is the taper per foot?
48. Using an outside micrometer caliper, explain how distances D and E in Fig. 4-40 may be accurately determined.
49. Explain how the 1.8755″ — 1.8750″ shoulder length in Part No. 3, Fig. 26-21, may be determined with an outside micrometer caliper.
50. Explain how the 1 7/16″ depth of the 5/16″ diameter hole in Part No. 3 Fig. 26-21, may be measured.

CHAPTER 5

Classification A

1. Describe the process of open-bed molding.
2. Name and explain five disadvantages of open-bed molding.
3. What is meant by draft allowance? Why is it necessary and how is it determined?

4. What is meant by shrinkage allowance? How are the final dimensions of the pattern calculated?
5. Explain the composition and function of core oils.
6. What are the fields of application of green sand and dry sand molds?

Sketch or describe the following:

7. Core. 8. Pattern. 9. Flask. 10. Drag. 11. Cheek. 12. Cope. 13. Draw-plate. 14. Slick. 15. Molding board. 16. Riser. 17. Sprue. 18. Gate. 19. Pouring basin. 20. Core-box. 21. Ladle. 22. Vent. 23. Parting sand. 24. Cupola. 25. Chaplet. 26. Crucible.
27. What is the function of the limestone in a cupola charge?
28. Explain the operation of an oscillating electric furnace.
29. Explain the false-core method of molding a grooved sheave.
30. Explain the three-part flask method of molding a grooved sheave.
31. Explain the ring-core method of molding a grooved sheave.
32. Explain the process of sweep molding for objects having surfaces of revolution.
33. Explain the process of sweep molding in conjunction with the use of skeleton patterns.
34. Explain the application and limitations of chaplets.
35. Explain how a part may be molded by using a loose-piece pattern for a projection or boss.
36. Explain how a part may be molded by using a core to care for a projection or boss.
37. Explain the cause of and remedy for the usual casting defects.
38. Describe the usual methods of cleaning castings.

Classification B

39. A part is composed of two integral cylinders—one 9″ in diameter and 3″ high, the other 6″ in diameter and 6″ high. The part is to be made of cast iron with a ¼″ machining allowance, and is to be cast with the axis of the part in a vertical position. Make a sketch giving the final dimensions of the pattern.
40. A cast bronze bushing is 4″ in diameter and 6″ long, with a cored hole 3″ in diameter. If ⅛″ is required for machining allowance, give the final dimensions of the pattern if the part is cast in a vertical position.

In the following problems, sketch the pattern and any necessary cores, and sketch and describe the process of making a mold for the particular casting specified. Where dimensions are not given, consider the scale of the illustration as ¼″ = 1″.

41. Part No. 2, Fig. 26-21.
42. Frame *D* of the drill jig of Fig. 21-1.
43. The adjustable table of Fig. 25-14.
44. Part No. 1, Fig. 26-20.
45. The eccentric sleeve, Fig. 25-13.
46. The base or lower half of the housing, Fig. 3-10.

CHAPTER 6

Classification A

1. Upon what material characteristic does forging depend?
2. What are the respective fields of forging by hand and by machine?
3. Sketch and describe three types of blacksmiths' hammers.
4. What are the respective functions of the hardie and pritchel holes in an anvil?
5. Describe four types of blacksmiths' tongs and their use.
6. Describe four types of blacksmiths' formers and their use.
7. Describe and differentiate between upsetting and swaging.
8. Describe the process of hot punching.
9. Describe two methods of making bolt forgings.
10. Describe the process of forging an eyebolt from a solid bar.
11. By means of a sketch, describe the operation of a helve hammer.
12. By means of sketches, describe the operation of an hydraulic forging press.
13. By means of sketches, describe the principal elements of an open-gap punch and shear, omitting the details of operation of the clutch.
14. By means of sketches, describe the operation of a power press clutch that will permit a single stroke of the ram at one time.
15. Describe an angle-shearing attachment for a power press.
16. By means of sketches, describe a hole-punching attachment which may be used on a power press.
17. Describe the stages in hot riveting.
18. What is a hand gag?
19. What advantage has a pneumatically-actuated bucker-up over a dolly bar?
20. What is the difference between drifting and reaming holes?
21. Are structural joints calked? Explain.
22. Why is a cape chisel preferred for grooving metal in place of a cold chisel?
23. What is a holddown and why is it used?
24. Why is shop riveting preferred to field riveting?

Classification B

In the following problems, sketch and describe the operations and tools for forging the specific parts. Where dimensions are not given, consider the scale of the illustration as $\frac{1}{4}'' = 1''$.

25. Turnbuckle, Fig. 2-22.
26. Part *A*, Fig. 26-2.
27. Shaft, Fig. 3-11.
28. Structural wrench, Fig. 16-34 (scale $\frac{1}{2}'' = 1$ foot).
29. S wrench, Fig. 16-34.
30. Part *D*, Fig. 26-19.

CHAPTER 7

Classification A

1. Differentiate between the terms "blank, template, and development."
2. What is meant by the term "triangulation"?
3. What is a stake and what is it used for?
4. Differentiate between raising hammers and mallets.
5. Describe the operation of a power-actuated squaring shears equipped with a hold-down.
6. Describe the principle of operation of a bar folder.
7. Describe the operation of a roll forming machine, and show how the degree of curvature of the sheet may be altered.
8. Why are slip roll forming machines superior to plain machines?
9. Sketch and describe the principle of operation of a rotary shear.
10. What is the essential difference between a folder and a brake?

By means of sketches, describe the operation of the following rotary machine rolls:

11. Ogee beading. 12. Crimping. 13. Turning. 14. Slitting.

Classification B

15. Explain the process of forming part *T*, Fig. 20-20, from a circular sheet of copper by using a raising hammer and several raising blocks. The scale of the illustration is $\frac{1}{8}'' = 1''$.
16. Sketch the necessary developments for a sheet metal quart container of conical form.
17. Explain the necessary procedure in making a sheet metal section similar to Fig. 2-13, four feet long. Figure scale one-eighth size.
18. Explain the process of making and assembling the sheet metal portion of the sheave shown in Fig. 20-29, construction *A*, scale quarter size.

CHAPTER 8

Classification A

1. What are the three primary considerations in all machining operations?
2. Describe a machining application in which dimensional accuracy, as well as other considerations, is important.
3. What are the important stages in metal cutting?
4. Upon what does the energy expended in metal cutting depend?
5. By means of a sketch, differentiate between rake, relief, and lip angles on cutting tools.

6. In what manner does the position of a cutting tool affect the rake and relief angles in turning cylindrical work?
7. Differentiate between forming and generating surfaces.
8. Describe how conical surfaces may be generated.
9. Differentiate between cutting-up and climb-cutting.
10. What are the respective advantages of cutting-up and climb-cutting?
11. By means of sketches, differentiate between form-type and profile-type cutters.
12. Show how clearance, or side relief, may be obtained in form-type cutters.
13. Why are abrasive wheels used for metal removal?
14. What is the function of a bonding material in an abrasive wheel?
15. What is "smear" metal?
16. Why are ordinary "cut" surfaces sometimes unsatisfactory?

Classification C

17. What is meant by a "built-up" edge?
18. How is surface roughness measured?

CHAPTER 9

Classification A

1. What is meant by saw "set"?
2. Differentiate between cross-cut and ripsaw teeth.
3. Differentiate between back, compass, and coping saws.
4. Differentiate between inside and outside bevel gouges.
5. By means of sketches, differentiate between the method of setting and holding the plane iron in block and in jack planes.
6. Why is the block plane superior to the fore plane for finishing end grain?
7. Name three kinds of special hand planes and describe their application.
8. What are the respective advantages of twist drills and auger bits for wood boring?
9. What are the essential elements of an auger bit?
10. What is the difference between the solid-center and the double-twist auger bit?
11. What types of shanks are used for wood-boring tools?
12. What is trepanning?
13. Why are hole saws preferred to auger bits for large holes?
14. What advantage has a ratchet-type bit brace over a plain brace?
15. Can boards with bevelled edges be handled on a circular saw table? Explain.
16. Why are two-tooth inside cutters employed for dado heads?
17. Explain the principle of operation of a bandsaw.
18. What is the field of application of a bandsaw?
19. When is a jigsaw preferred to a bandsaw?
20. What is a fence? A cleaner tooth?
21. What are the respective fields of application of wood planers and wood jointers?

22. Describe the principle of operation of a wood planer.
23. What is the field of application of a wood shaper?
24. By means of sketches, show how a wood shaper can be employed for curved molding work.
25. Describe two types of wood shaper cutters.
26. By means of sketches, describe the essential features of a vertical spindle bench drill press.
27. Describe the principle of operation of a three-jaw universal drill chuck.
28. By means of sketches, describe the principle of wood-routing.
29. Describe the operation and application of a square-hole mortising chisel.
30. How may a mortise 3″ long and 1″ wide be cut with a 1″ square mortising chisel?
31. Describe the various types of bench drill spindles.
32. Differentiate between disc and belt sanding machines.
33. Differentiate between a matcher and a molder.
34. What is a lathe?
35. Describe the essential elements of a wood-turning lathe.
36. By means of sketches, describe the operation and construction of a lathe tailstock.
37. What is the essential difference between turning and facing?
38. What is the difference between the live and dead centers of a wood-turning lathe, and why are they unlike?
39. Why are wood-turning lathe dead centers hardened?
40. Describe the operation of turning a conical part on a wood lathe. Length 8″; end diameters 2″ and 3″.
41. Describe the operation of turning a tool handle.
42. How may a candlestick composed of opposite sectors of walnut and birch be turned on a wood lathe?

CHAPTER 10

Classification A

1. Name three methods of originating cylindrical holes.
2. Sketch and describe the essential elements of a two-lipped twist drill.
3. Describe the function of the margin, the point, the flutes, the lips, the web, and the shank of a two-lipped twist drill.
4. What type of hole results if the lips of a twist drill are of unequal length?
5. What type of hole results if the point angle of a twist drill is unsymmetrical with the axis?
6. Describe the operation and function of an upright drill press.
7. Describe the essential features of a vertical spindle bench drill press
8. What are the fields of application, and the operating advantages of a radial drill press?
9. Describe the essential features of a radial drill press.

10. How may a drill with a No. 2 Morse taper shank be held in a drill press spindle with a No. 4 Morse taper hole?
11. Describe two methods of holding and driving straight-shank twist drills.
12. Explain the application and functioning of a bayonet chuck.

Sketch the following and briefly indicate the function of each:

13. Drill collet. 14. Single-purpose drill chuck. 15. Vee block. 16. Straight-fluted drill. 17. Oil-hole drill. 18. Core drill. 19. Core drill with replaceable tip. 20. Rose reamer. 21. Knife reamer. 22. Expansion reamer. 23. Inserted-blade reamer. 24. Shell reamer. 25. Taper roughing reamer. 26. Shell reamer arbor. 27. Taper pin reamer. 28. Bridge reamer. 29. Subland drill. 30. Reversed counterbore. 31. Piloted countersink. 32. Center drill.
33. What is a number size drill?
34. What is a letter size drill?
35. What is the effect of misalignment of drill and work axes when the drill rotates and the work is stationary?
36. Like No. 35, with a stationary drill and rotating work.
37. What are the probable effects of incorrect drill feed rates?
38. What effect has too high a speed on drill points?
39. Why must drills or reamers with three or more cutting edges be employed for enlarging holes?
40. Why cannot core drills be employed for originating holes?
41. What is the essential difference between rose and finishing reamers?
42. Why are rose reamers generally used prior to using finishing reamers?
43. Sketch and describe the operation and function of a floating reamer holder for use in automatic machinery.
44. Sketch and describe the operation and function of a commercial floating reamer holder.
45. Why are floating reamers used for finishing holes?
46. Differentiate between adjustable and expansion reamers.
47. Why are shell reamers preferred to solid reamers in the larger sizes?
48. What is the advantage of a core drill with a removable tip?
49. What advantages have reamed over drifted holes in structural work?
50. Why are drilled holes superior to punched holes in pressure vessel work?
51. What is the essential difference between boring and core-drilling?
52. Sketch and describe the operation of a two-bit commercial boring bar.
53. Sketch and describe a two-lipped non-adjustable cutter boring bar.
54. Differentiate between counterboring, countersinking, and spot-facing.
55. Why are multi-cut drills used instead of drills and counterbores?
56. What is the difference between center drilling and countersinking?
57. Describe the necessity for, and the operation of reverse counterboring.
58. Differentiate between taper, plug and bottoming taps.
59. What are serial taps, and why are they used?
60. What is the function of a tap drill?
61. What is an interrupted-thread tap, and when is it used?
62. What are the applications and limitations of spiral-pointed taps?
63. What is a tapper tap, and what is it used for?
64. What are the advantages of collapsible taps?

Classification B

Describe the operations illustrated in the following figures; name and describe the machines and tools used, the method of holding the work, and give other relevant data.

65. Fig. 10-56. 66. Fig. 10-41. 67. Fig. 10-58. 68. Fig. 10-57.

Describe the necessary tools, machines and procedures required for the following operations, considering the scale of the original figure as one-fourth size unless otherwise specified.

69. Drilling, reaming, and assembling the taper pin in the pulley and shaft of Fig. 3-11.
70. Drilling and tapping the necessary holes in Part No. 3, Fig. 26-21.
71. Drilling the 25/64" holes, and facing the bosses in Part No. 1, Fig. 26-20.
72. Drilling and facing the bosses in the frame, Fig. 3-2.
73. A ½"-13-NC tapped hole required a 27/64" tap drill. What is the thread percentage?
74. A ¾"-10-sharp "V" thread employs a 41/64" tap drill. What is the thread percentage?

Classification C

75. What is the diameter of the plug at the end of the socket, and the taper per foot, in a No. 6 Morse taper?
76. What is the diameter of the plug at the small end, and the taper per foot, in a No. 6 Brown & Sharpe taper?
77. Describe the method of calculating the Jarno taper.
78. What is the taper per foot, and the diameter of the socket at the large end, in a 40 MM Standard taper?

CHAPTER 11

Classification A

1. What is the essential difference between an engine lathe and a wood-turning lathe?
2. What is the function of engine lathe back gearing?
3. By means of sketches show the change in rake and clearance angles of lathe turning tools for different settings with respect to the axis of the work.
4. What is the function of a reversing plate in an engine lathe?
5. Why is an engine lathe tailstock mounted on a saddle?
6. Why are dead centers hardened, while live centers are left soft?
7. How is power transmitted from the lathe spindle to the feed shaft?
8. How is power transmitted from the lathe spindle to the lead screw?
9. Differentiate between the motions of the cross slide and the compound rest.
10. Sketch and describe the conventional method of holding a lathe tool
11. How are lathe sizes determined?

12. What is a gap lathe, and why is it used?
13. Name three important methods of holding work in a lathe.
14. Describe the process of turning a cylindrical bar 8″ long and 2″ in diameter, from a piece of stock $2\frac{1}{8}$″ in diameter and $8\frac{1}{8}$″ long.
15. Describe the process of turning a blank for a fillister head screw $\frac{3}{4}$″-10-NC, 3″ long, with a head $1\frac{1}{4}$″ in diameter and $\frac{3}{4}$″ long.
16. Differentiate between independent and universal lathe chucks.
17. How does an air-operated chuck function, and where is it used?
18. Show by a sketch how chucks are attached to heavy-duty spindle noses.
19. Describe the operation and function of a draw-in collet chuck.
20. Why should left-handed filing be resorted to in lathe work.
21. Why are end-facing or squaring operations often performed before turning?
22. What is the essential difference between steady rests and follower rests?
23. Can a follower rest be used for multi-diameter work? Explain.
24. Name and describe three methods of turning tapers on a lathe.
25. A bar has a taper of 3″ per foot, and is 8″ long. How much set-over should the lathe tailstock have for turning the bar?
26. When are magnetic chucks used for lathe operations?
27. What method of taper turning would be used for facing a bevel gear blank?
28. A part has an overall length of 9″ and is composed of a cylindrical portion 4″ long and 2″ in diameter and a tapered portion whose diameter varies from 2″ to 1″. How much set-over should the lathe tailstock have?
29. Describe two methods employed for boring tapered holes.
30. Describe the process of cutting internal threads on a lathe.
31. How are triple-threaded screw helices correctly "started" when cutting these threads on an engine lathe?
32. Describe and differentiate between the three methods of metal removal when cutting threads on an engine lathe.
33. Describe the knurling process and differentiate between straight and cross knurling.
34. Differentiate between the button and disc methods of locating holes accurately.
35. Sketch a suitable mandrel, and describe the process of winding a conical spring on a lathe.
36. How may springs be wound on a lathe?

Describe the function of and sketch the following tools:

37. Rotating dead center. 38. Nut mandrel. 39. Solid mandrel. 40. Center gage. 41. Two-screw lathe dog. 42. Goose-neck tool. 43. Formed threading tool. 44. Safety lathe dog.

Classification B

Describe the operations illustrated in the following figures. Name and describe the tools used, the method of holding the work, and explain the operational sequence and other relevant data:

45. Fig. 11-46. 46. Fig. 11-39. 47. Fig. 11-49. 48. Fig. 11-44. 49. Fig. 11-43. 50. Fig. 11-45.

51. In Fig. 11-2, if gear *A* has 15 teeth, 5-pitch, and if gears *C* and *G* are 4-pitch with 12 and 48 teeth respectively, what will the back gearing ratio be?
52. In Fig. 11-2, gears *A*, *B*, *C* and *G* have 20, 80, 30 and 70 teeth, respectively, 6-pitch. What will the spindle speed be if the back gearing is engaged and the pulley rotates at 300 r.p.m.?
53. Describe the process of turning and finishing a cylindrical bushing 2″ inside and 2½″ outside diameter and 3″ long from a piece of bar stock 3″ in diameter and 3¼″ long.
54. Like No. 30, but using a casting with a 1¾″ cored hole instead of the bar stock.
55. Referring to Fig. 11-2, list the necessary gearing for cutting a ⅝″-11-NC thread on an engine lathe. Lead screw pitch 1/6″.
56. Like No. 55, for a 3″-2½ threads per inch, square.
57. List the necessary gears for cutting a thread with a 4 mm. pitch.
58. List the necessary gears for cutting a thread with a 6 mm. pitch.
59. Describe the button method of accurately locating the holes for the bushings *O* in the leaf *F* of the drill jig of Fig. 21-2. Scale approximately one-third size.
60. Describe the process of making from bar stock on a lathe the spindle of Fig. 3-11. Scale one-fourth size.
61. Describe the process of making from bar stock on a lathe the taper hole spindle of Fig. 9-22. Scale one-fourth size.
62. If, in Fig. 11-51, $X = 3''$, $Y = 3\frac{1}{4}''$, and $Z = 4\frac{1}{4}''$, find the diameters of the discs *A*, *B* and *C*.
63. A bell crank has three holes *R*, *S* and *T*. The center distance between *R* and *S* is 2¼″, between *S* and *T* is 2¾″, and the centerlines through *R* and *S* and *S* and *T* form an angle of 75°. Find the necessary disc diameters *A*, *B* and *C*, Fig. 11-51, for locating and boring.
64. Describe the process of finishing on a lathe the pulley, Part No. 2, Fig. 26-21.

CHAPTER 12

Classification A

1. Differentiate between shaping, planing and slotting, as regards relative tool and work motions.
2. Differentiate between forming and generating metal surfaces.
3. What are the essential features of a shaper?
4. Differentiate between a planer, a shaper and a slotter, as regards the field of application of each.
5. Describe the operation of cutting tee-slots on a shaper.
6. Sketch and describe a quick-return motion for a shaper.
7. Sketch and describe an hydraulic circuit for a shaper.
8. What are the advantages and disadvantages of hydraulically-actuated machine tools?

9. Describe the principle of operation of a planer
10. What are the respective fields of open-side and double-housing planers?
11. Describe the field of application of duplex table planers.
12. How may work be held on planer and shaper tables?
13. Why are slotter rams arranged to permit cutting at an angle with the vertical?
14. Describe the construction and function of gang planer tools.
15. Differentiate between gang and string planing.
16. Differentiate between boring machines and boring mills.
17. Describe the essential features and operating principles of a horizontal-spindle boring machine.
18. Describe the precision measuring device used on horizontal boring machines.
19. Describe the function and operation of the jig borer.
20. Describe several methods of finishing precision-bored holes.
21. By means of sketches, show how boring may be performed on an engine lathe.
22. Sketch three types of boring bars used in horizontal machines.

Classification B

Describe the operations illustrated in the following figures; name and describe the tools and machines used, the method of holding the work, the operation performed, and give other relevant data:

23. Fig. 12-31. 24. Fig. 12-18. 25. Fig. 12-13. 26. Fig. 12-23. 27. Fig. 12-19. 28. Fig. 12-20. 29. Fig. 12-9. 30. Fig. 12-8.
31 Describe the process of boring the holes for the bushings *O* in the leaf *F* of the drill jig of Fig. 21-2. Scale approximately one-third size. (In this procedure, the leaf *F* is assembled to the body of the jig before boring.)
32. Describe the process of planing a rectangular slide to be fitted with a taper gib. (See Fig. 3-8.)
33. Describe the process of planing and boring Part No. 1, Fig. 26-20.
34. Describe the process of accurately boring the bushing and stud holes in the drill jig of Fig. 21-1. Scale one-fourth size

CHAPTER 13

Classification A

1. Define the term milling.
2. How may milling machines be classified?
3. Differentiate between the old and new style arbors for holding and driving hole-type milling cutters.
4. Describe the methods of holding taper and straight-shank cutters in a standardized spindle end.
5. What advantages have coarse-tooth over fine-tooth cutters?
6. What advantages have spiral-tooth over straight-tooth cutters?

Sketch or briefly describe the following:

7. Helical mill. 8. Inserted-tooth face milling cutter. 9. Spiral-tooth end mill 10. Two-lipped slotting end mill. 11. Half-side milling cutter. 12. Straddle mills. 13. Screw arbor. 14. Interlocking cutters. 15. Concave cutter 16. Convex cutter. 17. Shell end mill. 18. Shell end mill arbor. 19. Fly cutter. 20. Formed-tooth saw.
21. What is meant by "rimming" a handwheel?
22. For what purposes is a rotary milling attachment used?
23. Differentiate between direct, plain, and differential indexing.
24. Describe the principle of operation of an index head.
25. Why are as many as eight or fifteen cutters required for cutting all gears of a given pitch?
26. Explain the process of cutting bevel gear teeth on a milling machine.
27. Explain the operation of an oscillating-head die sinker.
28. Explain the principle of operation of a duplicator.
29. Explain how a master die may be fabricated directly from the part for which the mold is to be made.
30. Describe the process of finishing a steel hemisphere on a die-sinking machine
31. Explain the field of application of a two-dimensional pantograph duplicator.
32. Why are three-dimensional pantographs used instead of duplicators?
33. It is desired to cut a spur gear with 95 teeth on a milling machine. Give the number of the hole circle and the number of spaces to which the sector should be set.
34. It is desired to cut a spur gear with 108 teeth. Give the number of the hole circle and the number of spaces to which the sector should be set.

Classification B

35. A milling cutter has 12 teeth and rotates at 80 r.p.m. What is its feed in inches per minute if each tooth takes a .002″ chip?
36. A milling cutter 6″ in diameter has a cutting speed of 40 feet per minute. What is its speed in r.p.m.?
37. A milling cutter ½″ in diameter rotates at 700 r.p.m. What is the cutting speed in feet per minute?
38. A milling cutter 2″ in diameter rotates at 90 feet per minute and has a feed rate of 4″ per minute. What is the feed in thousandths of an inch per spindle revolution?
39. By means of sketches, show the relative spindle position, and the table, knee, saddle, etc., position and motion in universal, Omniversal, plain and vertical-spindle column and knee type milling machines.
40. By means of sketches, describe the construction and principle of operation of a milling machine feed transmission system.

In the following, name the machines and tools used, describe the method of holding the work and the operational sequences, and give other relevant data. Scale ¼″ = 1″, unless otherwise specified.

41. Milling dovetail slides.
42. Milling keyways for Pratt & Whitney keys.

43. Milling slots in angle E, Fig. 11-43. (Scale $\frac{1}{8}'' = 1''$.)
44. Milling reamer flutes.
45. Milling handle groove in the eccentric of Fig. 25-13.
46. Milling the tee slots in the adjustable table of Fig. 25-14.

Classification C

47. Describe the operation of finishing grooved face cams on a milling machine using a rotary table and a special cutter.
48. Describe the operation of milling a helical groove with an angle of 30° in a large drum cam, using a spiral head.

Consult a standard handbook and, by means of calculations and sketches similar to those in Sections 170 and 173, verify the gearing and other data for the number of indexing divisions or the leads required in the following problems:

49. 241 divisions. 50. 359 divisions. 51. 278 divisions. 52. 361 divisions. 53. 2″ lead. 54. 5.168″ lead.

CHAPTER 14

Classification A

1. How may surface-finishing processes for machined surfaces be classified?
2. Define the term grinding.
3. What is a grinding wheel?
4. Describe the various types and kinds of abrasives.
5. Describe vitrified, shellac and resinoid bonds.
6. Describe the manufacture of silicate and of vulcanite wheels.
7. Differentiate between grain and grade in a grinding wheel.
8. How do work speeds affect finish in cylindrical grinding?
9. How does the area of contact affect grinding wheel selection?
10. What is the difference between wheel dressing and wheel truing?
11. Sketch two types of mounted diamonds for wheel truing.
12. Sketch and describe the principal features of a universal grinder.
13. Show by sketches how the external wheel and the internal grinding wheel in a universal grinder can be easily and successively applied to a chucked part, in which both the exterior and the hole are to be ground in one set-up.
14. Differentiate between plain and planetary internal grinding.
15. What is plunge-cut grinding?
16. Why is the bore of hollow cylindrical work generally ground prior to grinding the external surface?
17. What are the respective advantages of the two methods of grinding profile-type cutters?
18. By means of sketches, show how form-type cutters may be ground on a universal grinding machine.
19. Describe the various types of surface grinding machines.

20. Describe the construction and operation of a vertical-spindle surface grinding machine.
21. Describe the construction and functioning of a permanent-type magnetic chuck.
22. What are the respective advantages of permanent-type and electrified magnetic chucks?
23. What is the field of application of disc grinders?
24. What is the field of application of floor grinders?
25. Why are cutting tool edges stoned after sharpening?
26. Why are natural oilstones superior to artificial stones?
27. For what purposes are coated abrasives used, and in what forms may they be obtained?
28. What is the essential difference between polishing and buffing?
29. What is the definition and function of lapping?
30. What types of abrasives are used for lapping operations?

Sketch or describe the following:

31. Squaring lap. 32. Cylindrical lap. 33. Ring lap. 34. Wire brush. 35. Cup wheel. 36. Dished wheel. 37. Center-hole lap. 38. Taper-sided wheel.

Classification B

Describe the operations shown in the following figures; name the tools and devices used; describe the method of holding the work and the operational sequences, and give other relevant data:

39. Fig. 14-31. 40. Fig. 14-15 *C*. 41. Fig. 14-15 *D*.
42. Describe the process of grinding the necessary surfaces of Part No. 3, Fig. 26-21.
43. Describe the process of grinding the gaging surfaces of the snap gage, Fig. 17-16.
44. Describe the process of grinding the long cylindrical portion of the taper-hole spindle, Fig. 9-22. Scale one-fourth size.

Classification C

45. What is meant by a No. 36 U grinding wheel—using the Norton Company's system of grading?
46. Contrast the systems of nomenclature for grinding wheel grades used by various manufacturers.
47. What is meant by grinding allowance? How is it affected by the size of the work?
48. What cutting speeds are used for various types of wheels?

In the following select a suitable grade and grain of grinding wheel. Give the name of the wheel manufacturer, his recommendations for the particular operation, and other relevant data:

49. Rough-grinding cast iron bases.
50. Grinding hard rubber.

51. Hand-grinding taps and reamers.
52. Grinding chilled-iron dies.
53. Surface-grinding hardened steel.
54. Grinding small brass castings.
55. Grinding manganese steel.
56. Saw gumming.

CHAPTER 15

Classification A

1. What is the essential difference between soldering and brazing?
2. What is the essential difference between brazing and welding?
3. Differentiate between forge and resistance welding.
4. Differentiate between gas and electric-arc welding.
5. Describe the principle of operation of a gas torch.
6. Describe the essential procedures in gas welding.

Sketch the following welded joints:

7. Plug weld. 8. Rivet weld. 9. Double-welded vee butt joint. 10. Single-welded U-butt joint with backing-up strip. 11. 45° elbow pipe weld. 12. 90° slip-on elbow weld.
13. How may straight-line flame cutting of indefinite length be performed?
14. Describe the construction of a cutting head.
15. Describe the principle of operation of the oxygen lance.
16. What effect has electrode polarity in welding thin material?
17. Describe the "shielded-arc" electric welding process.
18. By means of sketches, describe the principle of operation and the advantages of a hand-operated welding positioner.
19. Describe the principle of Thermit welding.
20. What is the field of application of Thermit welding?
21. What is the essential difference between welding and metal-spraying?
22. Describe the principle of operation of a metallizing gun.
23. What is the field of application of hard-facing, and how is the process performed?
24. What is the purpose of stress-relieving welded structures, and how is it accomplished?
25. What methods are used for welded-joint inspection?
26. Describe the application of solder-type fittings.
27. Describe the essential principles involved in the use of solder-type fittings.
28. Describe the application of electric-furnace brazing.
29. By means of sketches, show how a flanged brass tube may be more conveniently and economically made by electric-furnace brazing than by threading and assembling.
30. What is the essential similarity between solder fittings and electric-furnace brazed joints?

CHAPTER 16

Classification A

1. What influences the selection of a suitable pitch for hacksaw teeth?
2. Describe three types of power saws for commercial metal cutting.
3. Differentiate between cold saws, friction saws, and abrasive cut-off wheels.
4. Describe the construction and cycle of operation of a power hacksaw with an hydraulic feed.
5. Why are *heavy-set* band saws superior to *light-set?*
6. Explain how a metal-cutting band saw may be used for internal cutting without cutting through from the exterior.
7. How may a metal-cutting band saw be used for cutting mating punch and die blocks, and why is this method preferred to the conventional method of making mating blocks?
8. Explain how a metal-cutting band saw may replace a die-set for short-run stamping work.
9. What is meant by the "cut" of a file, and how many types of cuts are there?
10. Sketch the three types of file "cut."

Describe or sketch the following file terms:

11. Length. 12. Tang. 13. Blunt file. 14. Taper file. 15. Safe edge. 16. Mill file. 17. Hand file. 18. Three-square file.
19. Differentiate between cross and draw filing, and indicate the field of application of each.
20. What is a file jig and how is it used?
21. Describe the construction of a continuous file band as used on a band saw.
22. For what purposes are rotary files employed?
23. Describe the function and application of portable electric tools.
24. Why are two-piece or chaser type dies preferred to solid dies?
25. What types of threads are difficult to cut with dies? Why?
26. Describe the construction and operation of releasing die holders.
27. Explain the function and application of self-opening die heads.
28. Describe the application of pipe-threading machines.
29. Describe the sequence of operations in pipe fitting.
30. What is a Stillson wrench, and why is it used for pipe fittings?

CHAPTER 17

Classification A

1. What are the essential differences between the mass-production system and the unit-production system?
2. Explain why interchangeability and precision are not necessarily synonymous.

3. What is meant by the principle of interchangeability?
4. What are the principal advantages and disadavantages of the mass-production system?

Define or describe the following terms:

5. Limit dimensioning. 6. Unilateral tolerance. 7. Allowance. 8. Interference. 9. Bilateral tolerance. 10. Clearance. 11. Selective assembly. 12. Interchangeable assembly.
13. What are the advantages of unilateral tolerances as compared with bilateral tolerances?
14. What tolerances are used for fractional dimensions and how is their specification taken care of?

Sketch and describe the application of the following:

15. Progressive limit plug gage for a hole. 16. Single-size snap gage. 17. Taper insert double-end gage. 20. Master gage for snap gages. 21. Progressive adjustable limit snap gage with single-block anvil. 22. Progressive adjustable limit snap gage with four buttons. 23. Plain ring gage. 24. Double-end thread plug gage. 25. Thread snap gage. 26. Combination gage for shoulder screw.
27. Describe a set of gages for a cylindrical slotted rod.
28. Describe a set of gages for a small crank.
29. Describe the function and operation of visual gages.
30. Describe the function and operation of a visual limit gage that may be used by comparatively unskilled operators.
31. What is a contour measuring projector, and for what applications is it employed?
32. How may a contour measuring projector be used for checking thread leads?

Classification B

33. Design a set of gages for Part No. 3, Fig. 26-21.
34. Design a gage for checking the location of the bolt holes, with respect to the shaft hole, for the flanged coupling of Fig. 3-14. Scale one-fourth size.
35. Design a set of gages for the bushing shown in Fig. 25-9, at the completion of the turret lathe operations. Scale approximately one-third size.
36. Design a gage for checking the location of the holes in Part *W*, Fig. 21-1, after drilling. Scale one-fourth size.
37. Design a combination gage for a collar head screw.
38. Design gages for a drill collet.

CHAPTER 18

Classification A

1. What are the essential differences between mass-production and unit-production casting and foundry processes?

2. Why are production patterns made of metal?
3. What special allowances must be made by the pattern-maker in making the original wooden pattern for metal patterns?
4. What is matchplate molding?
5. Describe an inexpensive method of making matchplates.
6. What is a snap flask, and why is it used?
7. What are the advantages and disadvantages of matchplate molding?
8. Describe the suspended-core method of molding pistons.
9. Describe the balanced-core method of molding pistons.
10. What are the advantages of stacked or vertical molds?
11. What are the advantages of dry-sand-core molds?
12. What is a strainer core, and where is it used?
13. Why are pencil gates used?
14. How are cores made in production foundries?
15. What foundry operations may be performed by the aid of molding machinery?
16. Sketch or describe a spray pattern plate.

Sketch and describe the following types of foundry machinery and indicate their field of application and their advantages and limitations:

17. Squeezer machine. 18. Contour squeezer. 19. Jolt rammer. 20. Shockless jolt rammer. 21. Sandslinger. 22. Pattern-draw machine. 23. Rollover-table machine. 24. Stripper-plate draw machine. 25. Jolting-squeezing-stripping machine. 26. Power jolt-rollover-draw molding machine.
27. What is the difference between permanent and sand molds?
28. What is a gravity-feed casting and how is it made?
29. Explain the process of slush casting.
30. What is a die-casting?
31. Explain the function and operation of a rotary permanent-mold machine.
32. What metals are generally used for die-casting?
33. Explain the operation of an air-actuated die-casting machine.
34. Explain the operation of a plunger-type die-casting machine.
35. Differentiate between solid-sprue and split-sprue gated die-casting dies.
36. Explain the operation of a die-casting die and carriage.
37. Discuss the various types and styles of die-casting dies, and indicate their fields of application.
38. How are die-casting dies vented?
39. Describe the principle of operation of an injection molding machine for plastic molding.
40. What is the field of application of plastic compression molding?

Describe the following types of plastic molds, and indicate their applications and limitations:

41. Flash mold. 42. Positive mold. 43. Positive stripper mold. 44. Floating-chase mold. 45. Sheet mold. 46. Tube mold.
47. What is a preform and why is it used?
48. Describe the construction and operation of a centrifugal mold for casting ring gears.

49. Describe the process of centrifugally-casting iron pipe.
50. What advantages has centrifugal casting over sand casting?
51. What are die-casting inserts and why are they used?
52. Why should the most important part of a casting be placed at the bottom of the mold?

CHAPTER 19

Classification A

1. By means of sketches, differentiate between two-high, two-high reversing, and three-high rolling mills.
2. Describe the important features and the details of operation of a three-high rolling mill.
3. What is meant by the term "continuous mill"?
4. What is a "repeater"?
5. Describe the cupping process of manufacturing seamless tubing.
6. Describe the piercing process of manufacturing seamless tubing.
7. Explain the operation and application of a Stiefel mill.
8. Using sketches, describe the process of rolling structural angles.
9. Describe the cold-drawing of wire, using sketches.
10. Explain the sequence of operations in the manufacture of hot-extruded steel cylinders with closed ends.
11. Describe the manufacture of extruded lead pipe.
12. Explain the sequence of operations in extruding zinc-alloy tubes for toothpaste.
13. Using sketches, explain the sequence of operations in the manufacture of automobile engine valve stem forgings by extrusion.
14. What is the essential difference between drop forging and machine forging?
15. Describe the operation of a board drop.
16. Differentiate between rolling mill rolls and forging rolls.
17. Using sketches, explain the sequence of operations in the manufacture of automobile engine valve stem forgings by the upsetting process.
18. Using sketches, explain the sequence of operations and the necessary dies in drop forging a single-throw crankshaft.
19. Describe the rotary cold-swaging process.
20. Using sketches, describe and differentiate between two methods of machine forging a spur gear blank 6″ in diameter with a 1″ diameter hole, and a hub 2″ in diameter and 2″ long. Use a 1″ diameter bar for one method and a 2″ diameter bar for the other.
21. Using sketches, explain the sequence of operations in machine forging a single-throw crankshaft.
22. Describe the process of machine-forging large hexagonal nuts.

Classification B

23. Describe the process of manufacturing bars 6″ long and ½″ diameter, with a ½″ square head 2″ long, on the rotary cold-swaging machine.

24. Describe the process of drop forging the box wrench of Fig. 16-34. Scale one-sixth size.
25. Describe the process of drop forging the structural wrench of Fig. 16-34. Scale one-eighth size.
26. Describe the process of machine forging the wrench socket shown in Fig. 16-34. Scale approximately one-sixth size—blind hole.
27. Describe the manufacture of diamond wire-drawing dies.
28. Describe the process of rolling structural channels from a rectangular billet.
29. Describe the process of rolling I-beams from a rectangular billet.

CHAPTER 20

Classification A

1. Differentiate between the terms shearing and blanking.
2. Differentiate between the terms bending and drawing.
3. Why are open-back inclinable presses often preferred to vertical presses?
4. What is meant by the term bolster plate?
5. When are double-crank presses preferred to single-crank?
6. What type of press is used for cutting off casting sprues?
7. Describe the principle of operation of a knuckle-joint press.
8. Describe the principle of operation of a press actuated by an eccentric and pitman.
9. What are the respective fields of application of eccentric-and-pitman presses, knuckle-joint presses, and hydraulic presses?
10. What is the essential difference between single and triple action presses?
11. Differentiate between blanking and piercing dies.
12. Why is a combination die often preferred to a progressive die? Which is more expensive in first cost? In operational time?
13. By means of a sketch, show the principle of operation of a sub-press die, with punches held by Cerromatrix.
14. Sketch a subpress progressive die for blanking and piercing plain washers.
15. Explain the application and operation of a universal perforating die.
16. Explain the operation and application of a rubber-pad die.
17. Explain how a metal-cutting bandsaw may be employed as a substitute for a die set on short-run work.
18. By means of a sketch, explain how forming dies for short-run work may be made from Cerromatrix or similar material.
19. Describe three methods of producing armature laminations, and indicate the field of application of each method.
20. Discuss the relative advantages of chain and staggered circular blank layouts.
21. Describe the operation and field of press brakes.
22. By means of sketches, show how varying degrees of sharpness of bend may be obtained with a four-way die in a press brake.
23. Show the sequence of operations in producing a cold-formed tee on a press brake.
24. For what types of work are multi-slide machines used?

25. Describe the operational sequence of a multi-slide machine.
26. Why are blank holders used in deep drawing operations?
27. What is redrawing, and when is it required?
28. Describe the operation and construction of a combination blanking and drawing die.
29. Describe two types of bulging dies.
30. Describe the operation of a simple redrawing die.
31. Describe the operation of a curling and wiring die.
32. What is the field of application of metal spinning?
33. Describe metal spinning.
34. Describe the process of spinning a conical cup with a curled edge. The cup is made from a plate 6″ in diameter, and has a depth of 2″ and an outer diameter of 4″.
35. Differentiate between sizing, coining, and extruding processes.
36. What advantages and limitations has the sizing process?
37. What important design detail will facilitate coining procedure?
38. Describe the process of cold-extruding small links with hubs.
39. Describe the process of cold extruding a part with an integral rivet.
40. Where are spun rivets used?
41. Describe two methods of rivet spinning.
42. Explain the application of nut-inserts.

Classification B

Describe the process of forming the following sheet steel sections on a press brake:

43. Fig. 2-13. 44. Fig. 2-15.
45. Describe the sequence of operations and show the successive die positions *P*, *Q*, *R* and *S* in Fig. 20-18.
46. Design a set of dies, and show the sequence of operations in forming part *T*, Fig. 20-18, from steel wire. Scale one-fourth size.
47. Design a bending die for producing the fastener shown in Fig. 9-34.
48. Design a die for blanking and forming part *T*, Fig. 20-20. Scale one-fourth size.
49. By means of a layout, determine the most economical arrangement of a layout for blanking semi-circular sheet steel parts, 15/16″ radius, with a 1/16″ minimum clearance between blanks. The strip width may be either 6″, or slightly greater, depending upon whether chain or staggered blank layouts are used. Give figures as to the relative percentages of waste or scrap material.
50. Like No. 49 for a tee-shaped sheet steel part 1/16″ thick. The width of the stem and the crossbar of the tee are ¼″; the total height and width of the tee are 1¼″ and 15/16″.
51. Why is a spinning operation rather than a die operation employed for curling the edges of the vee-belt sheave shown in Fig. 20-29?
52. Which of the two constructions, *A* or *B*, Fig. 20-29, is likely to be less expensive for large-scale production? Explain.
53. Describe the operational sequence and the dies shown in Fig. 20-15.
54. Design a die for a double-action press for forming small seamed cylinders from 1/16″ stock, ½″ inside diameter, ¾″ long.

CHAPTER 21

Classification A

1. What is the essential difference between a jig and a fixture?
2. Describe the construction and function of drill jig bushings.
3. Why should drill jigs be supported on four, and not three, feet?
4. What advantages have commercial drill jigs as compared to those made entirely in the tool room? What disadvantages?
5. Differentiate between multiple drill heads and gang drills.
6. Differentiate between the universal joint and arm type of multiple spindle drill, and the cluster-plate type of multiple spindle drill.
7. What is the essential difference between drilling machines and boring machines?
8. Describe the construction and operation of a gear chuck.
9. Describe the operation of mass-production boring machines.
10. Why are tungsten-carbide or diamond tool bits used for boring soft as well as hard materials?

Classification B

Sketch and describe the function and operation of the drill jigs shown in the following:

11. Fig. 21-1. 12. Fig. 21-2. 13. Fig. 21-4. 14. 21-5. 15. Fig. 21-16.
16. Design a knife reamer for "line-reaming" the bearing holes in the frame of Fig. 3-2 after the bushings are assembled. Scale half size.

Design a drill jig for drilling the indicated holes in the following:

17. Fig. 26-20, Part No. 1—two 25/64" holes. 18. Fig. 26-21, Part No. 3—two 5/16" holes. 19. Fig. 25-13—nine holes in base. Scale one-fourth size. 20. Fig. 25-13—five holes in cap. Scale one-fourth size. Use sub-land drill for combined drilling and counterboring.

CHAPTER 22

Classification A

1. Differentiate between hand-operated, semi-automatic, and fully automatic turning and facing equipment.
2. What is the field of application of turret lathes?
3. Describe the essential parts of a turret lathe.
4. Describe the indexing and locking operational cycle of a turret.
5. Describe the mode of operation of a turret lathe bar chuck.
6. What is the difference between saddle-type and ram-type turret lathes?

Sketch or describe the following turret lathe tools:

7. Stub boring bar. 8. Knee tool. 9. Slide tool. 10. Adjustable turning head. 11. Forged cross slide tools. 12. Adjustable holder for turning and facing operations.
13. Sketch and describe circular forming cutters.
14. Sketch and describe a straight form cutter, and show how the inclination of the cutter affects the profile of the work and the cutter.
15. Differentiate between semi-automatic lathes and automatic chucking machines.
16. Differentiate between the Bullard Mult-Au-Matic and Contin-U-Matic.
17. For what classes of work are vertical turret lathes adapted?
18. What is meant by operational divisibility, and how does it affect production rates?
19. Differentiate between automatic screw machines and automatic chucking machines.
20. Differentiate between single and multiple spindle automatic bar machines.
21. Describe the operation and function of hollow mills.
22. Describe the function and operation of box tools.
23. What are the respective advantages of the Brown & Sharpe and the Cleveland Automatics? What are their fields?
24. Sketch a plate cam for a B & S automatic, and explain how it can be quickly and conveniently made for short-run lots.
25. What is the function of a bar carrier on an automatic screw machine?
26. What are the respective fields of application of single-spindle and multiple-spindle automatics?

Classification B

Describe the operations shown in the following; name the tools and machines used; describe the method of holding the work, and give the operational sequence and all other relevant data:

27. Fig. 22-21. 28. Fig. 22-20. 29. Fig. 22-23. 30. Fig. 22-18. 31. Fig. 22-55. 32. Fig. 22-51. 33. Fig. 22-53. 34. Fig. 22-33.

Describe the process of making the following parts on a turret lathe; sketch the tool layout and describe the operational sequence. Scale half size unless otherwise specified:

35. Fig. 3-2, Bearing—from bar stock. 36. Fig. 3-2, Pulley—from bar stock. 37. Fig. 26-21, Part No. 3—from bar stock. 38. Fig. 26-21, Part No. 2—from a casting.
39. Describe and contrast two methods of finishing the grooves in multiple-vee belt sheaves.
40. By means of sketches, describe the process of machining small fillister head screws on a single spindle automatic equipped with a stop, a drill, a die, and a single form tool.
41. By means of sketches, describe the process of machining square head set screws with cup points from square bar stock on a single-spindle B & S automatic.

42. By means of sketches, describe the process of machining small shoulder screws on a four-spindle automatic bar machine.
43. By means of sketches, describe the process of making, in multiple on an eight-spindle automatic, knurled nuts similar to that shown in Fig. 2-22.

CHAPTER 23

Classification A

1. Describe the essential differences between bed-type and column-and-knee type milling machines.
2. By means of sketches, differentiate between simplex, duplex and triplex bed-type milling machines.
3. Describe the principle of operation of "rise-and-fall" bed-type milling machines.
4. Describe and differentiate between drum-type milling machines, planer-type milling machines, and rotary-table-type milling machines.
5. Describe the principle of internal planetary milling.
6. Describe the principle of external planetary milling.
7. Describe the principle of operation of an external thread-milling machine.
8. What are the fields of application of thread milling?
9. What is the essential difference between milling fixtures and drill jigs?
10. What is the purpose of using a latch in combination with false vise jaws?
11. Design a set of false jaws for a vise for holding and milling the nut opening of an open end wrench forging, in which the opening is at an angle of 90° to the straight handle.
12. Design a set of false jaws for a vise for milling the slots in four ¾"-10-NC fillister head screws.
13. By means of sketches, explain the principle of hobbing.
14. By means of sketches, explain how a triangular section may be hobbed in a cylindrical shaft.
15. What is the essential difference between spur-gear and worm-gear hobbing?
16. By means of sketches, show the set-up for hobbing a helical gear with a 30° left hand helix, using a right hand hob with a 10° helix angle.
17. Name and describe the advantages and disadvantages of cutting gears with a gear shaper cutter, in contrast to hobbing or form-cutting.
18. Describe the principle of gear shaping.
19. Why are helical gears that are cut on a gear shaper made with two or three standard helix angles, and with standard pitches in the diametral plane? What advantage has this method of measurement over the method of measuring pitches in the normal plane?
20. Describe the process of cutting herringbone gear teeth with sharp apices.
21. Explain how disc cams may be generated on a gear shaper.
22. Explain the process of generating bevel gear teeth.
23. What is the essential difference between grinding spur gear teeth with a flat-sided wheel and with a form-type wheel?
24. Explain the purpose and principle of gear-tooth shaving.
25. What are the respective advantages and fields of application of the parallel-axis and the crossed-axis methods of shaving?

26. What is the purpose of gear-tooth lapping and when is the process employed?
27. Describe the principle of gear tooth lapping.
28. Describe the application and operation of a gear burnishing unit.
29. By means of sketches, describe the production milling of plate cams.
30. By means of sketches, describe the production milling of cylindrical drum cams.
31. To what simple hand operation is broaching analogous?
32. What are the respective fields of push and pull broaching?
33. Describe the essential operating features of a screw-actuated broaching machine.
34. Describe the process of broaching helical grooves in rifle barrels.

Classification B

Sketch and describe the function and details of the fixtures shown in the following:

35. Fig. 21-20. 36. Fig. 23-16. 37. Fig. 23-6. 38. Fig. 23-39.

Describe the operations, fixtures, and cutting tools used in the following:

39. Fig. 23-10. 40. Fig. 23-3. 41. Fig. 23-17. 42. Fig. 23-37.
43. Design a fixture for boring the stud hole in Part No. 1, Fig. 26-20. Consider the 25/64" holes already drilled.
44. Design a fixture for finish-broaching the jaws of the S wrench shown in Fig. 19-18. Scale one-fourth size. The operation is performed after a preliminary rough-milling operation to remove the fin, and separate operations are required for each jaw.
45. Design a broach for push-broaching the hole in the box wrench of Fig. 16-34. The original circular hole is ¾" diameter; the short diameter of the hexagonal hole is ¾".
46. Design a milling fixture for milling the top of the base and the recess on the pillow block of Fig. 3-3. Scale one-quarter size. The work may be located from the edges of the base. Select and sketch suitable cutters for this operation.
47. Design a milling fixture for finishing the semi-circular slots in the frame of the adjustable angle illustrated in Fig. 25-14. Scale approximately one-fourth size. The slots are to be milled from the solid, in several cuts, using a two-lipped slotting mill in a vertical milling machine equipped with a rotary table.

CHAPTER 24

Classification A

1. Describe the operation of an internal grinder with an automatic sizing device or dial indicator.
2. Describe the operation of the Heald Gage-matic.
3. What is the Nortonizer and how does it function?
4. Why must the grinding wheel be trued to a special curved profile when grinding Acme threads with a high helix angle?

5. Why are double-head machines used for crankshaft grinding?
6. Describe the principle of operation of a cam grinder.
7. Describe the operating principles of a through-feed centerless grinding machine.
8. Describe the operating principles of an internal centerless grinding machine.
9. Discuss the three possible work and wheel positions in centerless grinding.
10. Discuss the two possible work and wheel positions in internal centerless grinding.
11. What is the essential difference between honing, lapping, and Superfinishing?
12. Describe the process of internal honing.
13. Describe the construction and function of a manually-operated hone for finishing cylinder bores.
14. What cutting speeds and what production rates are possible in automotive honing practice?
15. How may cylindrical holes with side openings, and blind holes, be finished by honing?
16. What types of abrasive material are used in mechanical lapping?
17. Describe the construction and operation of a vertical lapping machine which uses bonded abrasive wheels.
18. What types of laps are used for gage lapping?
19. How are true lap surfaces obtained in vertical lapping machines?
20. What are the essential differences between cylindrical centerless lapping and centerless grinding?
21. Why are both wheels swivelled in centerless lapping?
22. Explain the theory of Superfinishing.
23. Describe the construction and function of a Superfinishing head which may be used in conjunction with an engine lathe.
24. Describe the principles of operation of a centerless Superfinishing machine.
25. Why may only full-skirt type pistons without relief be Superfinished?
26. How may crankshaft crankpins be Superfinished?

CHAPTER 25

Classification B

1. Describe the process of relieving form-type milling cutters.
2. Explain the sequence of operations and the manufacture of ground-thread taps.
3. Explain the sequence of operations and the manufacture of twist drills.
4. How are the oil holes in oil hole drills produced?
5. Describe the process of automatically threading hexagonal or square nuts with a hook tap and a special machine.
6. Describe the process of threading nuts with a tapper tap.
7. Describe the sequence of *first* operations in producing the flanged bushing of Fig. 25-8.
8. Describe the principles and construction of the *second* operation machine of Figs. 25-11 and 25-12.

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